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Edited for the Council by J. LAURENCE PRITCHARD, Honorary Fellow

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NOTICES

Election of Members

The following members were elected at a Council meeting held on November 13th:—

Fellow.—H. N. Wylie.

Students.—C. E. T. Maguire, H. A. Miles, G. Ponsonby, H. C. de M. Seaman.

Foreign Member.—J. L. Merrill.

SCOTTISH BRANCH.—*Member.*—B. H. Alexander.

Lectures

Owing to the dislocation of work and loss of some of the records, as a result of the recent earthquake, the lecture by a representative of the University of Tokyo announced for February 7th, 1924, will not take place.

It will be replaced by Squadron Leader Maycock's paper on "Airmanship at Sea," which was originally announced for November 29th.

Research

A statement of the views of the Council on progress in research with particular reference to the Helicopter prizes announced by the Air Ministry, will be found on another page.

Air Congress Report

The Report of the International Air Congress, London, 1923, which contains several papers additional to those read during the Congress as well as verbatim reports of all the discussions, is now being printed and will become available towards the end of the month. It will be obtainable from the Society's offices, price £1 5s. 0d. (£1 to members of the Congress), postage extra.

Forthcoming Arrangements

Wednesday, December 5th, 8.30 p.m.—*Cambridge University Aeronautical Society.*—Major H. E. Wimperis, "Some Aeronautical Problems."

Thursday, December 6th, 5.30 p.m.—*Newcomen Society.*—Mr. Ivor B. Hart, A.F.R.Ae.S., "The Scientific Work of Leonardo da Vinci."

Tuesday, December 11th, 5.30 p.m.—Council Meeting.

Wednesday, Dec. 12th.—*Royal United Service Institution.*—Wing Com. Edmonds, "Air Strategy."

Friday, December 14th, 6.0 p.m.—*Institution of Mechanical Engineers.*—Professor A. H. Gibson and Mr. A. Wright Baker, "Exhaust Valve and Cylinder Head Temperature in High-Speed Petrol Engines."

Thursday, Jan. 10th, 5.30 p.m.—Dr. L. Aitchison and Mr. J. D. North, "Materials from the Aeronautical Point of View."

W. LOCKWOOD MARSH, *Secretary.*

XUM

THE AIR MINISTRY HELICOPTER PRIZES

The Council have lately been devoting considerable time and attention to the attitude of the Air Ministry towards research and in particular to the Helicopter prizes now on offer.

It will be recalled by members that in January, 1922, a deputation of the Council waited on the then Secretary of State for Air (Captain the Hon. F. E. Guest, M.P.) urging "the need for better safeguards to prevent the submerging of applied scientific research in aeronautics by technical *ad hoc* experimental work" (AERONAUTICAL JOURNAL, Vol. XXVI., p. 43).

The Council regret to say that they feel that there has been no improvement since that time and that in fact the position is, if anything, worse. The recent performances of American aeroplanes in speed, endurance and climb, which are the direct results of applied research, cannot fail to invoke comparison of an unfavourable nature with regard to British progress during the same period.

The Council of the Society have had certain correspondence with the Air Council relative to the prize to the value of £50,000 for helicopters. Such prizes, in the view of the Council of the Society, tend to give a wrong view of the relative values of serious research work on well established lines and such highly speculative experimental constructions as the helicopter.

The helicopter has on several occasions lately been the subject of discussions before the Society, the outcome of which has been the confirmation of the earlier impression that its limitations are such as to render expenditure on it unjustified in view of the amount of research work of an urgent nature which is required for the development of aeroplanes and airships. So far from being likely to solve the main problems of flight, the Council believe that the helicopter introduces more difficult problems. It depends for its safety even more than the aeroplane on freedom from power-plant failure and introduces extremely difficult problems of management and control. In the Council's view such questions as, for example, the definite diminution of power-plant failures, the control and stability of aeroplanes, the increase in the carrying capacity of aeroplanes, and navigation when the pilot is unable to see the ground are of immeasurably greater importance than the development of the helicopter. They also believe that the risks to life in any helicopter so far proposed will be vastly greater than in any type of aeroplane in use.

The Council are confident that members of the Society would endorse these views, which were laid before the Secretary of State for Air (the Right Honourable Sir Samuel Hoare, C.M.G., M.P.) by the Chairman and Vice-Chairman at a recent interview.

PROCEEDINGS

SECOND MEETING, 59TH SESSION

A meeting of the Society was held in the rooms of the Royal Society of Arts, John Street, Adelphi, London, on Thursday, October 18th, 1923, Colonel A. Ogilvie (Chairman of the Society) presiding.

Squadron Leader R. M. HILL, M.C., A.F.C., read the following paper:—

THE MANŒUVRES OF INVERTED FLIGHT

CONTENTS

Part I.—Introduction

(1) Definition of inverted flight.
(2) Reasons for investigation of inverted flight.
(3) Nature of this kind of experiment.
(4) Brief Outline of its History.

Part II.—Inverted Flight

(1) General Remarks.
(2) Methods of attaining the inverted position.
(3) The effect of the controls in inverted flight.
(4) Resuming normal flight.
(5) The slow roll.

Part III.—Special Inverted Manœuvres

(1) The inverted spin.
(2) Possibilities of the inverted loop.
(3) Conclusions.

PART I.—INTRODUCTION

1 *Definition of Inverted Flight*

In the following paper it will be convenient to adopt the definition of inverted flight used by the Accidents Committee in R. & M. 617 (Advisory Committee for Aeronautics), "Reports on the behaviour of aeroplanes when flying inverted, with special reference to some accidents on 'A,'" which was as follows:—"In normal straight flight the pressure of the pilot on his seat is equal to his weight. During inverted straight flight he would hang on his belt with an equal force. It is therefore considered useful to call inverted flight such flight only as occurs when the weight of the pilot no longer presses on his seat."

2 *Reasons for Investigation of Inverted Flight*

(*a*) During the latter part of the war an unduly large number of accidents had occurred in the training of pilots in aerobatics on unstable aeroplanes, such accidents being 50 per cent. in excess of similar ones on stable aeroplanes. The Accidents Committee had investigated the problem and as a result had issued R. & M. No. 617 (January, 1919), which commences as follows:—

I. INTRODUCTION.—During recent months a tendency has been observed in a number of accidents to "A" aeroplanes to assume the inverted position consequent usually on some error in flying. A feature was the apparent difficulty and frequent failure of the pilot to right the aeroplane. The Committee was therefore requested to consider the cases put forward and to investigate the flight of aeroplanes in the inverted position, with special reference to this particular type."

The analysis contained in R. & M. 617 went far to dispel the obscurity surrounding these accidents, and the conclusions arrived at were illuminating both to designers and pilots; based however, as they had to be, on inference from the general stability characteristics of aeroplanes rather than on the recorded experience of deliberate inverted flight, they required that such experience should be urgently sought. In the light of this experience it can now be said that these conclusions have received nothing but support from actual experiment.

As many of the accidents had been fatal, the pilots who had been able to supply information about the phenomena of inverted flight consistent enough for reasonable interpretation were few. Flying opinion was so divergent that even those who had made a habitual practice of flying inverted had failed to crystallise definite ideas on the subject. Such general lack of knowledge and the accompanying inability to distinguish real from imaginary risk, resulted in a loss of perspective that was injurious to flying morale.

The first and main reason for the inverted flying experiments undertaken at the R.A.E. was the necessity of testing and, if necessary, supplementing the argument of R. & M. No. 617. Only by throwing the maximum possible light on the causes of these accidents could they be eliminated in the future.

(*b*) While it was recognised that the accidents referred to must frequently have been caused by a failure on the part of the pilot to appreciate the characteristics of his aeroplane, it was suspected that the behaviour of an unstable aeroplane when inverted was such as to make the human failure far from unnatural; and even that under certain conditions the control might be inadequate for the recovery of normal flight. Cases more simple to understand were known to have occurred in which the pilot, either because he was so insecurely belted that he fell from his seat in the inverted position too far to be able to reach his controls, or because he was suffering from the mental and physical effects of involuntary inversion, or both, was unable to recover before striking the ground. On the other hand there appear to have been no cases where structural failure in the air could be directly attributed to manœuvres in the inverted position. This was certainly not because the loads that might be imposed on aeroplanes by inverted flying manœuvres had been specifically taken account of in design.

The second reason for the inverted flying experiments was the importance of forming an idea of the magnitude of the loads in inverted flying manœuvres, the possibility of which had not previously exerted a direct influence on stress calculations.

(*c*) The progress of the inverted flying experiments not only continued to clear away the doubt connected with past accidents on unstable aeroplanes, but opened up new avenues of thought. The idea that an unstable aeroplane flew inverted only too easily and was in some conditions difficult to bring back to normal flight, had its converse—that inverted flight on a stable aeroplane was difficult, if not impossible, to achieve.

The third reason for the experiments, a reason that as they developed became more cogent, was the desirability of analysing the behaviour in inverted flight of aeroplanes differing in stability characteristics, and the consequent formation of a sound tradition in a new sphere of aerobatics. The fear of involuntary inversion would pass away; the pilot would equip himself for handling his aeroplane

intelligently in any position it might happen to assume; better still, he would deliberately accustom himself to every possible attitude of flight, so quickening his sense of the niceties of aerial manœuvre that his descriptions of inverted flight, unlike those extracted from pilots whose senses the alarming experience of being inverted suddenly and without warning had blurred, would spring from a cool determination to observe, and thus have at least a fair chance of aiding scientific theory.

3 *Nature of this kind of Experiment*

It was impracticable at the outset to devise a programme of the precise form or sequence of the experiments. The stimulus was present in that unstable aeroplanes were known to have been the cause of a considerable waste of lives. Too little, however, was known about inverted flying to give any pilot definite instructions as to what he should do or how far it was safe to go. All that could reasonably be done with models, and with deductions from the behaviour of various types of aeroplane in normal flight, had been done. Until pilots could be found to reproduce intentionally the difficulties occurring in inverted flight, and describe them intelligently, the solution of the problem would remain as far off as ever.

The first step therefore was to secure the co-operation of pilots who either possessed some knowledge of inverted flight or were keen to learn about it, and leave it to their initiative to push ahead in their own way. Rather than urge them to confine themselves to any particular way of experimenting, I hoped that by stimulating their natural desire to develop skill in inverted flying, results, almost unconsciously, would come; and that miscellaneous information gathered from a number of pilots throughout a considerable period, would, when pieced together, form a more or less continuous whole. In grouping these results I have paid more attention to their place in relation to the experiments than to an adherence to chronological order.

4 *Brief Outline of its History*

The experiments on inverted flying followed naturally from previous experiments on the spinning of many types of aeroplane, and on the behaviour in looping of certain unstable aeroplanes, with which trouble had occurred. This line of thought found practical embodiment in an attempt to eliminate the undesirable characteristics of instability evident in the Sopwith "Camel" without spoiling its flying qualities from the service point of view; and a Sopwith "Camel" was modified by having its wings moved back and the weight redistributed, to bring the C.G. relatively further forward and gain longitudinal stability. The comparative experiments that were carried out on it are described in T.1457. They stopped short of actually flying it inverted.

The standard and modified Sopwith "Camels" formed the nucleus of material on which the experience of various pilots, some of whom had already had experience of inverted flight, and others of whom were subsequently trained, could be brought to bear. In the autumn of 1919 Flight Lieutenant Bulman, M.C., A.F.C., experienced both in flying a standard Sopwith "Camel" in war and in training war pilots, commenced experimenting and submitted a paper T.1440. He described his initial attempts at attaining the inverted position, both by half looping and half rolling, the aeroplane's behaviour in an inverted stall, and his attempts to reproduce the consequences of a failed loop.

So impressed was he with the accidents he had witnessed in the training of pupils, that he tried for some time to reproduce the inverted spin which he knew had frequently been a feature of these accidents, but without avail. In the autumn of 1920 Flying Officer Gerrard, D.S.C., one of the most experienced

pilots in the Service on Sopwith "Camels" and "Snipes," joined the R.A.E. He had succeeded in carrying out inverted spins intentionally, and, as far as is known, was the only pilot who had done so up to that time. He was able to demonstrate the method to Bulman, who immediately went up and successfully reproduced the inverted spin.

Meanwhile Bulman and Flying Officer Sainsbury, A.F.C., had both been flying inverted on the "Bat Bantam," and in the summer of 1920 they had succeeded in performing the first half of an inverted loop on this aeroplane. Bulman continued to enlarge his experience by flying inverted on the Sopwith "Snipe." From the autumn of 1920 onwards Bulman and Flying Officer Scholefield, D.C.M., commenced to fly inverted on the S.E.5A, an aeroplane that possesses a marked degree of longitudinal stability; and, although it had not up to that time been considered possible, they were able to maintain steady inverted flight on this type. Finally, the inverted spinning experiments were extended to the modified Sopwith "Camel" and the S.E.5A.

Part II.—Inverted Flight

1 *General Remarks*

It is known that an aeroplane which is longitudinally stable in normal flight will tend to be unstable in inverted flight, that is, it will drop its nose and return to its stable trimming speed in normal flight, if its balance is such that one exists. On the other hand an aeroplane that is longitudinally unstable in normal flight, if its balance permits, always tends to reach and maintain a condition of stable equilibrium inverted. As indicated in R. & M. 617 the important factor in settling these characteristics is the position of the C.G. relative to the wings. The more stable an aeroplane is in normal flight, the more difficult is the pilot's task of maintaining the inverted position, and *vice versa*. It is therefore relatively easier to fly unstable aeroplanes like the Sopwith "Camel" and "Snipe" inverted than stable aeroplanes like the S.E.5A. The "Bat Bantam," which is about neutral in stability at normal flying speeds, falls between the two extremes.

While the stability characteristics discussed above are the chief determinant of an aeroplane's behaviour, its balance has a most important effect on the ease of inverted flying, or alternatively the ease of recovery. The disposition of the Sopwith "Camel" to remain inverted is weakened by the standard practice of rigging it tail heavy in normal flight, whereby a tendency towards self-righting is introduced. When the "Camel" was rigged so as to balance correctly in normal flight, accidents occurred; for its inclination to follow its natural stability characteristics and remain inverted was thus allowed greater freedom. An aeroplane that is balanced to be nose heavy in normal flight will always, irrespective of its stability characteristics, be easier to fly inverted than one that is balanced to be tail heavy. If, therefore, inverted flight is attempted on a stable aeroplane, it is desirable, should the tail incidence be adjustable, to give the tail its maximum incidence in order to produce nose heaviness in normal flight, and a corresponding tail heaviness in inverted flight that will tend to overcome the aeroplane's natural self-righting properties. If the nose heaviness in normal flight thus produced becomes excessive, it is necessary to compromise, and about two-thirds of maximum tail incidence should be given.

To control his aeroplane effectively the pilot must, as it were, sympathise with its flying qualities. If he treats the aeroplane as something foreign to himself, he tends to make a purely mechanical use of the controls not in harmony with its flying qualities. If, however, he studies its motion closely he will find that its properties of balance, its stability characteristics, or the gyroscopic effect of its engine may be employed to relieve his control surfaces of a considerable part of their work, thus allowing them a margin of effectiveness to be acquired

FIG. I
PERSPECTIVE VIEW OF PILOT'S CONTROLS.

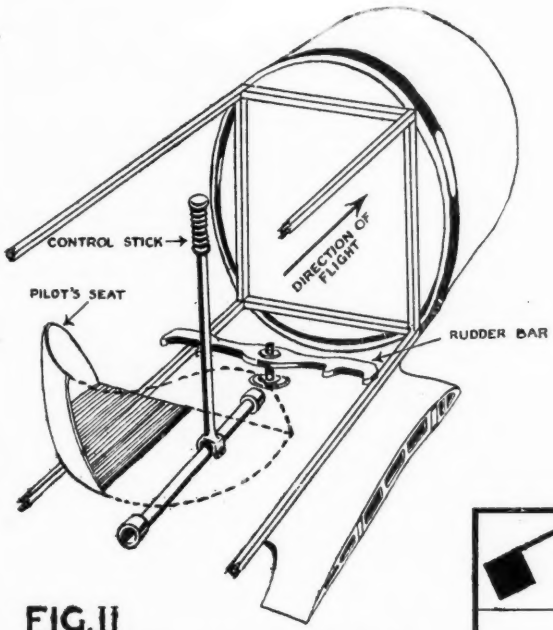
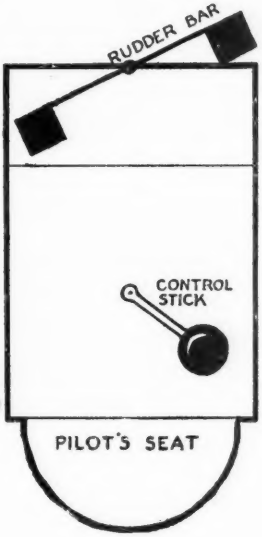


FIG. II
CONVENTIONAL DIAGRAM OF CONTROL STICK AND RUDDER BAR POSITIONS USED TO ILLUSTRATE THE CONTROL POSITIONS IN THE DIAGRAMS OF THE VARIOUS MANOEUVRES.



in no other way. More especially in an unstable aeroplane, a large number of the pilot's control movements are movements made to damp various kinds of motion which, though originally excited by the use of the controls, are yet the result of the aeroplane's natural propensities. This feature of control is important in inverted flying where the controls are as a whole less effective, and where perhaps a given manœuvre may depend entirely for its success on utilising them to the best advantage. Bearing this in mind the pilot will realise that if with his controls he excites a motion, which the qualities of the aeroplane are such as to stimulate, the longer he allows the angular velocity of the aeroplane to increase, the more difficult his task of damping the motion becomes; so much so that he may be compelled to abandon his original manœuvre and temporarily allow the aeroplane its own will.

To handle his aeroplane in accordance with the above considerations the pilot requires, apart from his instruments, which it is somewhat difficult to use consistently, some point or points of reference. Normally he refers the angular movement of his aeroplane to the ground; and it is of the first importance that the method he acquired of visualising his attitudes in normal flight should be applied to inverted flight. He may experience a temporary sensation of confusion similar to that felt in a loop or roll, while turning himself upside down. But once having attained the inverted position neatly, having allowed the belt to take his weight, and having experienced the satisfaction that it is really doing so, he will feel quite secure and the mental distress will disappear. He will, moreover, realise with some surprise than he can judge the exact attitude of the aeroplane by the horizon, and to some extent read his instruments. After half a minute or so he will probably feel the blood running to his head; it is, however, quite possible for a pilot to accustom himself to hanging inverted for considerable periods without experiencing any severe effects.

In each of the following sections I shall first indicate broadly the classes of control movement which govern all inverted manœuvres with all types of aeroplane, and then attempt to describe the refined differences of control movement that belong to aeroplanes of different stability characteristics (see Figs. I. and II.).

2 *Methods of Attaining the Inverted Position*

(a) General

Before practising inverted flight on any particular aeroplane it is essential that the pilot should familiarise himself with the standard manœuvres of looping, spinning, rolling, and rolling off the top of a loop. The last manœuvre is especially valuable in teaching him that an aeroplane is incapable of being manœuvred on the top of a loop if the speed has been allowed to drop too much.

There are two normal methods of attaining the inverted position; by means of a half loop, or a half roll. That of the inverted half loop is discussed in Part III. (*2*).

If the pilot intends to attain the inverted position by means of a half loop, he should loop the aeroplane several times and watch his airspeed indicator all the way round. In a normal loop the speed frequently falls to between 40 and 50 m.p.h. just on top of the loop. This speed is well below the stalling speed of the aeroplane when inverted, which may be 65 or 70 m.p.h. It is therefore essential that the half loop prior to inverted flight should be commenced, if the speed on the top of the loop is to be adequate, at a higher initial speed than that for a normal loop.

To commence inverted flight, the pilot pushes forward the control stick approximately half way through the loop to prevent the nose from dropping. With some aeroplanes he may experience difficulty in knowing just when to

push forward the control stick; with others he may have considerable latitude, and inverted flight will flow naturally from the half loop. If he pushes it forward too soon, the aeroplane may stall inverted; if too late, it will have gone too far into an inverted dive. The highly unstable aeroplane may possibly cause trouble if the control stick is pushed forward too soon, as any unpleasant characteristics peculiar to this class are accentuated near the inverted stalling speed. With such aeroplanes therefore it is wiser to be on the late side in pushing forward the control stick. If, with the more stable types, the control stick is not pushed forward at the right moment, the self-righting tendency will at the worst cause the aeroplane to drop its nose and come out in a straight inverted dive.

The above method lends itself more readily to a stationary-engined aeroplane in which the pilot experiences practically no gyroscopic effect tending to slew it about on top of the half loop. With a rotary-engined aeroplane the pilot must exercise a greater amount of care. In performing the loop he will find that the gyroscopic effect of the engine will necessitate rudder to counteract it. As soon as he commences flying steadily inverted the gyroscopic effect will disappear; and unless he is quick in centralising the rudder at the right moment, the aeroplane may roll out in a stalled condition or possibly fall into an inverted spin.

Attaining the inverted position by means of a half roll is a quieter manœuvre. It is possible to roll over upside down, fly inverted for some time and roll out on to an even keel in normal flight without ever exceeding a speed of 80 m.p.h. or imposing any undue stress on the aeroplane. A great advantage of the half roll is that the pilot need never lose sight of the horizon, thus retaining a more continuous sense of where he is. To assume the inverted position he may use a very slow half roll, in the process of which he must, if he is to avoid a rather severe side-slip, turn slightly off his course. On the other hand he may half roll quickly on to his back. In this case he gives the ordinary control movements for the roll, commencing the manœuvre at from 70 to 90 m.p.h. This will induce the characteristic whirling motion associated with auto-rotation. As, judging by the horizon, he approaches the inverted position (how near depends on how easily the aeroplane rolls and how easily it can be checked) he must check the roll by pushing the control stick forward towards the dashboard, centralising the rudder, or giving a little opposite rudder, and at the same time taking off aileron. The amount he will have to push the control stick forward of the central position will depend mainly on the stability characteristics of the aeroplane. A few trials may be needed to give precision and grace to the manœuvre.

The pilot will probably discover that the most comfortable speeds for inverted flight lie between 70 and 100 m.p.h. When he first attains the inverted position he may find that he is almost stalled, in which case he must ease the control stick towards him to gain more speed and control; on the other hand he may find himself rapidly falling into an inverted dive, when he must push the control stick away from him. If he does not carry out these corrective movements quickly enough, he may experience a tendency, at least during his initial attempts, either to stall and topple over sideways, or to fall out in a dive. He should not be disappointed, but should practise until he acquires the necessary judgment to turn the aeroplane on its back cleanly, with enough speed to make it controllable, yet not so much as to induce a dive.

Before the behaviour of individual aeroplanes is dealt with, a note on the management of the engine is necessary. The petrol systems of aeroplanes do not make special provision for petrol supply to the engine when inverted. It is only by chance that in one or two aeroplanes petrol continues to be supplied to the engine; and independently of the petrol system a stationary engine with a float carburettor will cease firing almost immediately on inversion. Although the method of attaining the inverted position by means of a half loop is suited to stationary-engined aeroplanes on account of the absence of gyroscopic effect, the

XUM

wisdom of turning the aeroplane upside down with the stationary engine running and allowing it to cut out, is questionable. A certain amount of petrol is bound to be spilt out, the presence of which is undesirable inside the cowling. Unfortunately an aeroplane cannot be half looped on to its back without the engine running, and Bulman has frequently done this on the "Bat Bantam" and the S.E.5A for experimental purposes. If petrol can be supplied to it, a rotary engine with a block tube carburettor will continue to fire. The Clerget engine of a Sopwith "Camel" will continue to run for half a minute on petrol contained in the pipes between the tank and the engine. There is evidence to show that the B.R.2 engine of a Sopwith "Snipe" will, even at full throttle, run for a longer period still. Oil is nearly always spilt into the cowling, and on the Sopwith "Camel" I have had trays fitted to collect it.

(*b*) *Application to Particular Aeroplanes*

Standard Sopwith "Camel."—The standard Sopwith "Camel" may be inverted by any of the methods referred to above. Inversion by the half loop is attended by the difficulties arising from the gyroscopic effect of the engine, accentuated by the very small rudder. In the second quadrant of an ordinary loop, full left rudder is needed to keep this aeroplane from yawing to the right. The rudder moment, which is then just sufficient to hold the yaw in check, induces a skid to the right. If a loop on a "Camel" is observed by another aeroplane from behind, the "Camel," when held straight by its pilot, is seen to skid bodily sideways. The skid is not, however, appreciated by the pilot in the "Camel." On a stationary-engined aeroplane where there is practically no gyroscopic effect, the pilot knows he has looped straight if he re-enters his own backwash; if on a rotary-engined aeroplane he has held the nose straight he will be displaced laterally and pass it by. Apart from the gyroscopic effect just referred to, the "Camel," being rigged tail heavy, behaves sweetly in the first half of a loop. The pilot is merely concerned in releasing his pressure on the control stick and allowing the nose to rise up. By the time he is inverted the control stick is fully back, and the rudder is full across to the left. To commence inverted flight, it is sufficient to exert a gentle forward pressure on the control stick. At this moment the gyroscopic effect disappears suddenly, and, if the rudder is not centralised at once, the aeroplane will slew rapidly to the left. To perform this manœuvre correctly the pilot has to ensure that he has enough speed on top of the loop to prevent an immediate stall, and to co-ordinate his elevator and rudder movements sensitively. A misjudgment either of speed or of control movement is enough to spoil the manœuvre (see Fig. III.).

The above difficulties are reduced if inversion is attained by a half roll. The slow half roll seems most adapted to the flying qualities of the "Camel." In this manœuvre the pilot cannot, unless he sideslips severely, avoid yawing off his course; as however he yaws the other way in the half roll for recovery, he regains his initial direction of flight. The gyroscopic effect of the engine asserts itself, but is not so difficult to deal with. If the pilot rolls to the right, the nose is forced down; if to the left, it is forced up. As the rudder is so small, a right-hand roll is easier; for it is better that the nose should drop rather than rise if the limit of rudder control is exceeded. Again, the pilot has greater control over the speed than at the top of the half loop. A convenient speed at which to commence the half roll is between 70 and 90 m.p.h. at half throttle. In half rolling to the right the pilot gently but firmly applies right rudder and right aileron. The "Camel" begins to roll over and to turn to the right. In anticipation of the gyroscopic effect the pilot has previously lifted the nose slightly; as soon, however, as the rudder and elevator interchange functions, he commences to push the control stick forward and turning ceases. As the wings pass the vertical he maintains right aileron, gradually takes off right rudder, and pushes the control

stick more forward, until as he approaches the inverted position he takes off right aileron completely and finishes with the control stick slightly forward of the central position. The movement of the control stick amounts to an anti-clockwise circular sweep in the right-hand side of the cockpit. Bulman found that he was able in half rolling to push the control stick forward at an earlier stage, and thus to keep on his course better. When I tried this I induced a severe sideslip. As however Bulman usually rolls to the left and I to the right it is conceivable that the pilot's instinctive allowance for the gyroscopic effect forms a habit which

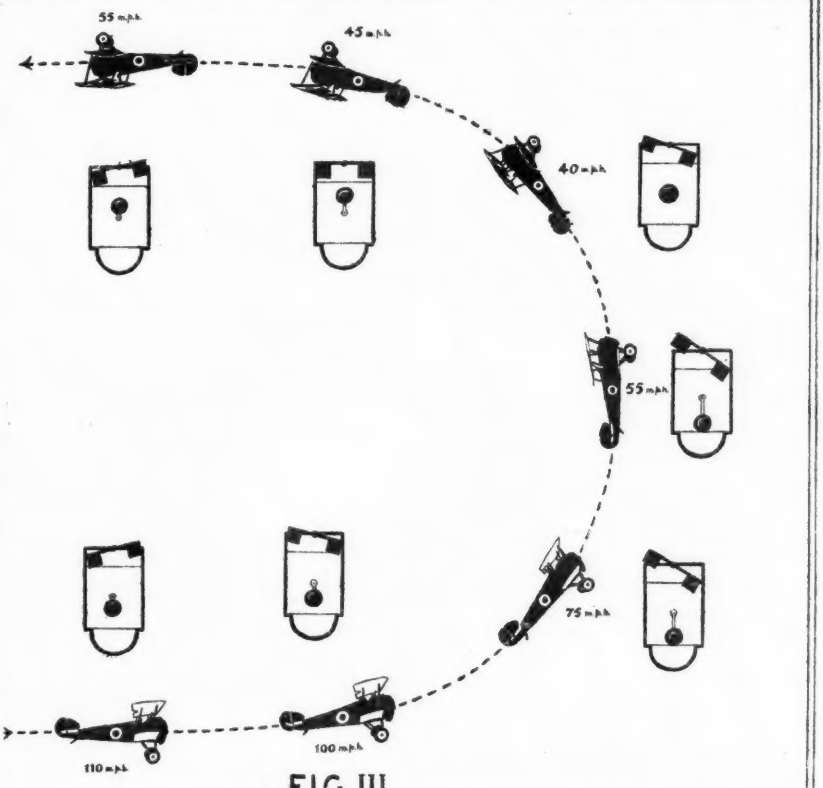


FIG. III

HALF LOOPING METHOD OF ATTAINING INVERTED FLIGHT

STANDARD SOPWITH CAMEL (UNSTABLE).

tends to persist even when the roll is made in the reverse sense to that which is customary. In this connection, it is interesting to note that nearly all pilots are right or left-handed, and that few experience the same ease in performing a complicated manœuvre to the left and right.

Modified Sopwith "Camel."—The modified "Camel" could be inverted either by half looping or half rolling. In an ordinary loop its longitudinal stability caused it to behave differently to a standard "Camel." Whereas during

the second quadrant the latter came over almost too quickly, the modified "Camel" had to be pulled over like the S.E.5A. Again, during the third quadrant, the modified "Camel" dropped its nose more quickly than the standard "Camel"; and therefore, in the half looping method of attaining the inverted position, the control stick had to be pushed forward more vigorously to keep the nose from falling. As in the standard "Camel," it was necessary to manipulate the rudder to counteract gyroscopic effect, but the likelihood of spoiling the manœuvre by a failure to centralise it as inverted flight commenced and the aeroplane became nearly stalled, was less.

I did not try the quick half roll for attaining inverted flight, though it would probably have been attended by no difficulty. In the slow half roll the controls had to be used, as a whole, more vigorously than in the standard "Camel." The movements were similar, with the exception that the control stick had to be pushed forward more definitely to keep the nose up as the aeroplane became inverted. In other words, the modified "Camel" showed characteristics similar to stable aeroplanes like the S.E.5A.

Sopwith "Snipe."—On the Sopwith "Snipe" Gerrard attained the inverted position both by half looping and half rolling, but he preferred the half loop. Unlike the "Camel," the "Snipe" has an adjustable tail; and as it is longitudinally unstable in normal flight its tail setting has a less important bearing on the case of flying it inverted than in the S.E.5A. At the same time, increased incidence on the tail does materially assist.

The half looping method is used as described for the "Camel," the commencing speed being 120 to 125 m.p.h., 10 to 15 m.p.h. in excess of that for an ordinary loop. At a point when the centre section spar appears to subtend about 10° to the horizon, the control stick is gently but deliberately pushed forward until the nose is steadied in the inverted position and held there. Gerrard says that he could keep his engine full on in inverted flight for a considerable period, and as a result was actually able to climb. If the engine were throttled back the nose fell somewhat and an inverted glide resulted. In this method the pilot is faced with a gyroscopic effect similar to that noticed in the "Camel," and has to use the same judgment in centralising the rudder at the commencement of inverted flight. Although the "Snipe" is fitted with a large rotary engine (the B.R.2), it has, relatively to the "Camel," a large rudder, which is better suited to counteract the violent gyroscopic effect. The centralisation of the rudder must be a direct consequence of the new conditions set up by the pushing forward of the control stick; and if, after pushing forward the control stick, the pilot is late in centralising the rudder, he stalls on his back with rudder on and introduces a set of conditions favourable to the inverted spin. (See Part III. (1).) Again, if the pilot pushes forward the control stick too late, the nose may have dropped too far, and the angular velocity of the aeroplane have increased so much that he will find it difficult to push the nose up again. At the same time an unstable aeroplane like the "Snipe" will always respond to this correction more kindly than a stable aeroplane; and as the involuntary inverted spin is to be avoided, the mistake of pushing forward the control stick too late is the less undesirable.

The slow half roll is most easily performed if the "Snipe" is flown at a speed in the neighbourhood of 100 m.p.h. Gerrard insisted on the necessity of selecting, if possible, some definite point on the horizon in order to stimulate the pilot's sense of direction. In half rolling to the right he pushed the control stick slowly and deliberately over to the right, meanwhile checking the tendency of the aeroplane to yaw off its course by gradually easing the control stick forward. With the steady application of right rudder the aeroplane then commenced to turn slowly over sideways. As the bank became steeper the control stick was eased more forward still, especially after the wings had passed the vertical. At this point Gerrard gradually reversed his rudder (gave left rudder)

until by the time that the aeroplane was completely inverted he had centralised it again. It will be noted that this use of reversed rudder in the final stages of the slow half roll differs from that in the "Camel," where the rudder was employed in varying degree but always in the same sense as the rotation of the aeroplane. Though unusual, this method was applied by Scholefield to the S.E.5A. It at least shows the difference of technique employed by various pilots. Gerrard's forward movement of the control stick in the "Snipe" before the wings passed the vertical agrees with Bulman's in the "Camel."

The quick half roll can also be performed on the "Snipe." The pilot, commencing at a speed of about 90 m.p.h., gives the ordinary control movements for a roll. Just before the aeroplane is half way round he pushes the control stick forward and centralises the rudder, or momentarily applies rudder opposite to the sense of rotation of the aeroplane. The effect of commencing the roll with the nose too much up or down is important, and a mistake in the attitude of the aeroplane in the initial stages may be irremediable. Once, however, the quick rolling motion has been excited, the elevator seems to be the essential factor in checking it; which is to be expected if this whirling motion is associated with auto-rotation. The rudder is only used to assist the elevator movement for the incorrect timing of which no skilful use of it can atone. As the control movements must be both sensitive and rapid, good judgment is required to perform this manœuvre with precision; and until practised the pilot, through having checked the whirling motion too early or too late, will be compelled to make subsequent corrective control movements that are detrimental to the grace of the manœuvre.

"Bat Bantam."—Bulman carried out a considerable amount of inverted flying on the "Bat Bantam." Its outstanding feature is its unusual controllability; in fact there is no other scout that equals it in the harmony of its elevator, rudder and aileron controls and the consequent effectiveness with which the pilot can use them. In longitudinal stability it is approximately neutral, and its flying qualities would not therefore be expected to be so favourable to inverted flying as those of the unstable types, the "Camel" and "Snipe." Perhaps in some degree this is true, but the unique effectiveness of its controls enables the pilot to carry out inverted manœuvres and maintain it in attitudes of flight that would be impossible with a scout of similar stability characteristics but with less control. In spite of its excellence of control, it has shown vice in a normal spin, not responding normally to the standard control movements for recovery. The inverted flying experiments, as far as they went, did not bring to light any further abnormal features.

The "Bat Bantam" can easily be half looped into the inverted position; and as it possesses a radial engine, practically no gyroscopic effect is felt. The engine ceases to fire almost immediately on inversion. The usual degree of care has to be taken to push forward the control stick at the right time to start inverted flight; to maintain it the control stick has to be held slightly more forward than in the "Camel" or "Snipe." Except for the difference in control stick position and for the absence of rudder movement to counteract gyroscopic effect, the control movements are similar to those for the unstable aeroplanes.

The "Bat" is also exceptionally straightforward to roll either slowly or quickly. Its responsiveness allows the pilot more latitude in his control movements; and if a mistake is made in allowing the nose to drop or rise too much it can more easily be rectified. In other respects the control movements do not differ essentially from those in the "Camel" and "Snipe."

S.E.5A.—For inverted flight on the S.E.5A, which is longitudinally stable in normal flight, the best position for the tail adjustment is two-thirds forward. Fully forward it would obviously do the maximum to assist inverted flight, but the excessive nose-heaviness that it causes in normal flight introduces an awkward

condition at the commencement of inversion and during the final stages of recovery. Before inverting himself by the half looping method Bulman tried a series of normal loops, watching the airspeed indicator all the way round. Whether the loop was commenced at 100 m.p.h. or 120 m.p.h. the speed at the top did not exceed 50 m.p.h. He finally commenced his half loops for inversion at 115 m.p.h., waited till the aeroplane was just over the top of the loop, pushed the control stick right forward and throttled his engine down. The engine appeared to fire for 10 to 15 secs. after inversion; but if the inverted glide was prolonged the propeller stopped, even though the airspeed indicator showed 80 m.p.h. In any case the aeroplane stalled immediately on inversion, and the stick had to be held firmly forward while the nose dropped and the aeroplane gained speed. The greater the speed at the top of the loop, the less was the stalled drop; under average conditions the nose only fell 15° to 20° from the horizontal.

Bulman and Scholefield both performed the slow and quick half roll for inversion. They commenced the slow half roll at 75 to 85 m.p.h. at about half throttle, but throttled right down on inversion; for if the throttle was left open the engine restarted with a violent jerk during the recovery. Bulman gave rudder and aileron in the desired sense of rotation, and after the wings had passed the vertical pushed the control stick fully forward. As he approached the inverted position he took off aileron and rudder. Schofield differed by pulling up the nose slightly at the commencement of the manœuvre; and instead of continuously applying rudder until nearly inverted, gave rudder during the initial stages, centralised it as the wings passed through the vertical, and then gave it again in the same sense. He also found that he could apply it in the opposite sense after the wings had passed the vertical, which corresponds to Gerrard's experience on the "Snipe." The aeroplane did not approach stalling at any time, and Bulman, though he experienced a small amount of sideslip, found remarkably little tendency to yaw off his course. Scholefield however found that if he did not allow some yaw he experienced considerable sideslip. All the control movements in this manœuvre, allowing for the firmness required with the S.E.5A, were comparatively slow and gentle (see Fig. IV.).

Bulman commenced the quick half roll in a similar way to the ordinary roll, by giving aileron and rudder in the desired sense of rotation and pulling the control stick back, with the exception that he made these control movements rather more gently. When nearing the inverted position he pushed forward the control stick, took off aileron and centralised the rudder. At the commencement of inverted flight he found that the aeroplane was as much stalled as when looping into the inverted position. This could be mitigated to some extent if the half roll could be commenced with no more backward movement of the control stick than was just necessary to induce the rolling motion. In manœuvres such as the quick roll, which seem to involve auto-rotation, the elevator, in controlling the angle of incidence, is the important factor in governing the motion.

3 *The Effect of the Controls in Inverted Flight*

(a) General

The feature of inverted flying that made the most forcible impression on me was the distortion of the pilot's sense of speed. The inefficiency of the wings in inverted flight causes the aeroplane to fly at an angle of incidence considerably greater than that for a corresponding speed in normal flight, and the pilot to receive the impression that the speed is lower than is actually the case. If the engine is off the gliding angle is relatively poor and the aeroplane loses height more rapidly than he expects. Added to this the aeroplane stalls inverted at a higher speed, sometimes as much as 30 per cent. in excess of its stalling speed in normal flight.

The pilot cannot consider the effect of the controls until he has made absolutely certain of being able to use them. For this he must be properly supported by a shoulder strap belt. Unless his belting arrangements are as perfect as he can make them, he feels insecure; and, if he slips from his seat, a violent jerk of the aeroplane may render control temporarily impossible. With a properly fitting belt, the actual use of the controls is no more difficult than in normal flight. If the pilot intends to fly inverted, he should fasten his shoulder straps so that in normal flight he is slightly constrained. Then on turning over he will

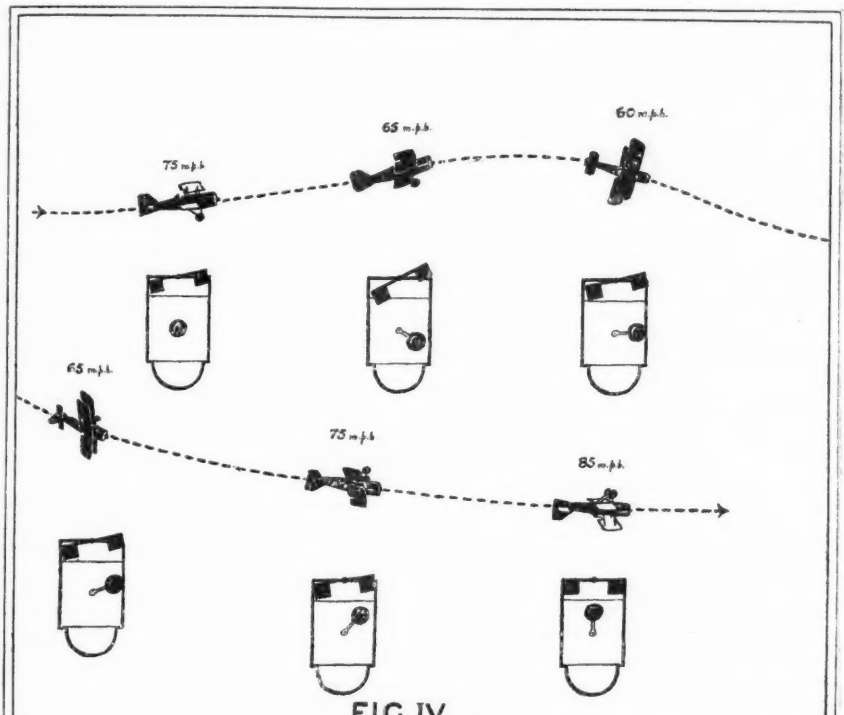


FIG. IV
SLOW HALF ROLL.
HALF ROLLING METHOD OF ATTAINING INVERTED FLIGHT.
SE5A (STABLE).

find that he is just held comfortably to his seat. Provided that he is securely belted in, he should not feel the want of toe straps on the rudder bar. The Sutton shoulder strap belt is, in spite of certain imperfections, the most satisfactory belt that I know of.

The control movements during inversion, though simple to visualise, are less easy to describe. The confusion arises from the difference in point of view of the pilot as he hangs inverted, and an observer on the ground. It is hardly necessary to add that in normal flight these points of view do not clash. If longitudinal control during inversion is considered from the ground observer's point of view, the effect of the elevator is reversed; to push the nose of the aero-

plane up, lose speed and approach stalling, the pilot pushes the control stick forward and away from him; to depress the nose (tilt it earthwards) and gain speed, he pulls the control stick back and towards him. The aeroplane answers to the control quite sensitively as long as the speed is kept at least 5 or 10 m.p.h. above stalling.

Now consider lateral control. If in *normal* flight the left wing is dropped by a bump, the pilot pushes the control stick to his right (away from the dropped wing) and depresses the left aileron to bring it up. If in *inverted* flight the left wing drops (equivalent from the pilot's point of view to his right wing) he pushes the control stick to his right and depresses the left aileron. It will thus be seen that if a wing drops, in order to bring the aeroplane on to an even keel he pushes the control stick towards the dropped wing, not, as in normal flight, away from it. From this it might be expected that aeroplanes would be difficult to hold on an even keel when inverted. The pilot will be agreeably surprised to find that this is not in general the case, neither should he experience much tendency to drop a wing if the speed is kept reasonably above stalling. His sense of balance will not desert him, he has a good view of the horizon, and after a little practice it is not difficult to keep the wings parallel to it.

If the co-ordination of the lateral and rudder controls is considered, it will be seen at the outset that a right-hand turn from the pilot's point of view is a left-hand turn as viewed from the ground. Right rudder to the pilot appears as left rudder from the ground. To perform a left-hand turn, say from north to west (from the pilot's point of view a right-hand turn) the pilot pushes with his right foot (thus putting on left rudder as viewed from the ground) and pushes the control stick to his left, thus raising the left aileron and depressing the right. Whereas in normal flight he gives aileron in the same sense as rudder, in inverted flight he gives it in the opposite sense; for a right-hand turn in normal flight, right stick and right rudder; for an inverted right-hand turn from the pilot's point of view, left stick and right rudder; and from the ground, right stick and left rudder. The control movements as described sound confusing. What actually happens is this—to produce a rotation about the aeroplane's longitudinal or vertical axes, the pilot pushes the control stick or the rudder bar in the direction that conforms to the desired sense of rotation, in a similar way to normal flight.

Time spent by the pilot in studying the effect of the controls will increase the certainty with which he can use them when he is actually in flight. To visualise the effect of the controls on the motion of the aeroplane, he will find it of assistance if he uses a small cardboard model with control surfaces that may be bent as desired. During his initial efforts at inverted flight he may also find it helpful to go up on a day with a well-defined cloud layer at about 4,000ft. He can then invert himself below the cloud layer; and by imagining this cloud layer to be the ground and *vice versa,* his control movements become simpler to understand. He uses his elevator control as if he were flying normally; to "depress" the nose, that is, tilt it towards the cloud layer which is now his "ground," he pushes the control stick forwards, losing speed however instead of, as in a normal dive, gaining it. If one wing "drops" (towards the cloud layer), to regain an even keel he pushes the control stick away from the "dropped" wing, as in normal flight. It is only when he comes to turn that the discrepancy remains. He pushes with the foot in the same sense as he wishes to turn, but instead of banking as he does in normal flight, he has to bank apparently the opposite way. He then feels as if he were on the "outside" instead of on the "inside" of the turn.

To summarise, the elevator control is reversed, but is on the whole fairly instinctive. The chief thing to be noted about it is that the movement which causes the aeroplane to gain speed in normal flight causes it to lose speed in

inverted flight, and *vice versa*. The aileron control is reversed, is the least instinctive, and to some pilots occasions slight difficulty at first. To the pilot the rudder control is not reversed, for he always gives rudder in the sense in which he wishes to turn; it is his idea of direction of the turn that is reversed.

(*b*) *Application to Particular Aeroplanes*

Standard Sopwith "Camel."—I flew the standard Sopwith "Camel" inverted and found that although it answered less sensitively to the elevator than in normal flight, the difference was less than I expected. I was unable to fly it slower than 65 m.p.h. inverted, at which speed it stalled. To fly inverted at any given speed the position of the control stick is slightly forward of that for the corresponding speed in normal flight; at 75 m.p.h. inverted the control stick is just forward of the central position. As far as I could detect, at low speeds the lateral control disappeared first, and near stalling the aeroplane showed a strong tendency to drop the right wing when inverted. If I could not check this dropping at an early stage the aeroplane frequently fell out from the inverted position in a half roll with severe sideslip. I found it quite possible to watch the airspeed indicator when inverted and fly steadily at a given speed. The tendency of the right wing to drop was particularly noticeable just after the half roll to become inverted.

I attempted to examine the stability characteristics inverted with engine off. The aeroplane was tail heavy in normal flight, and seemed to have a stable trimming speed at about 90 m.p.h. in inverted flight with engine off. This I investigated by abandoning the control stick when inverted, meanwhile steering with the rudder. The aeroplane settled down to what appeared to be a steady glide at 90 m.p.h. with "hands off." This observation, however, should be accepted with the greatest caution, owing to the shortness of the period during which the aeroplane could be allowed to glide while the trimming speed was under observation. The trimming speed was observed by producing an artificial disturbance in the neighbourhood of the supposed attitude of balance and investigating the nature of the oscillation set up. During inverted flight this is not an easy matter, as it is a physical strain to remain inverted for a sufficiently long time. It seemed however that if the control stick were pushed forward and released the speed tended to rise again towards 90 m.p.h.; and what is more important, if the control stick were pulled slightly back and released the speed tended to drop and the nose to rise; in other words the aeroplane actually wanted to remain inverted. Nevertheless the control force required to upset this condition was very small, and the "Camel" is not highly stable inverted.

The inverted stall is a matter of interest. If the "Camel" is stalled in the inverted position, it drops its nose quite definitely and shows the stalling characteristics associated with longitudinal stability; whereas in normal flight its stall shows the characteristics associated with instability, and is of a delayed and gradual character.

Modified Sopwith "Camel."—The modified "Camel" was longitudinally stable, and although tail heavy with engine on, with engine off it possessed a stable trimming speed between 60 and 70 m.p.h. After attaining the inverted position I at once noticed the difference in control stick position as compared with the standard "Camel." The control stick, instead of being just in front of the central position, was three-quarters way forward, in addition to which a noticeable control force had to be exerted to keep the nose from falling, and the aeroplane from commencing an inverted dive. The response was also less sensitive than on the standard "Camel." I then tried an inverted stall on the modified "Camel." I pushed the control stick full forward against the dashboard, and found that I could not fly slower than between 70 and 75 m.p.h. At this speed the lateral control became doubtful, and the right wing tended to drop. The

aeroplane, however, did not become properly stalled, neither did the nose heaviness decrease. At the slightest relaxation of pressure on the control stick, the nose fell and the airspeed increased. While I found it possible actually to induce an inverted spin on this aeroplane, I experienced no tendency for it to spin on its back involuntarily, even after a deliberate mishandling of the controls.

Sopwith "Snipe."—Gerrard and Bulman state that the Sopwith "Snipe" shows similar characteristics to the standard "Camel" in inverted flight. Unfortunately no detailed observations were made of the airspeed at stalling nor of whether the "Snipe" showed a stable trimming speed inverted. It responds if anything more sensitively than the "Camel" to the elevator control, and the use of the adjustable tail can be made to assist inverted flight. Like the "Camel," the position of the control stick had to be just forward of central. For a scout the "Snipe" possesses a large span, and an impression of its relatively sluggish lateral control is forced on the pilot by the "flickiness" of the longitudinal control consequent on its short fuselage. The "Snipe" showed on the whole less tendency to drop a wing near the inverted stall, and was therefore, in spite of its lateral control, easier to fly inverted at low speeds. Its relatively large rudder also assisted the maintenance of an even keel. As it is longitudinally unstable in normal flight, the same care had to be taken with the control stick in forward positions when the rudder was on.

"Bat Bantam."—Although approximately neutral longitudinally in normal flight, and with no tail adjustment, the "Bat Bantam" was found to be exceptionally controllable when inverted. Bulman actually preferred it to any other aeroplane. Its general response to control movements in all attitudes of flight examined, except that of a normal spin, was so straightforward as to give a pilot great confidence in his initial efforts. While the control stick had to be more forward of the central position than in the unstable types, there still remained sufficient margin of control to prevent the nose dropping unexpectedly.

The "Bat Bantam," due to its heavy loading, stalled inverted at as high a speed as 73 m.p.h., about 3 m.p.h. in excess of the S.E.5A. This difference in the lowest speed at which the two aeroplanes could be flown in inverted flight corresponds roughly with that of their stalling speed in normal flight. The inverted stall of the "Bat Bantam" differed from that of the "Camel"; the latter stalled sharply, the former hesitated and sank. While it must be admitted that the pilot can always produce, by handling the controls sharply or gently, a considerable variety in the kind of stall on any given aeroplane, beneath the variety he can usually detect certain permanent qualities which characterise the particular type. That the "Bat Bantam" hesitated and sank during the inverted stalling process may be accounted for by the fact that, being more stable than the "Camel" in normal flight, it showed less stable characteristics in inverted flight. Incidentally, its aileron and rudder controls were so evenly balanced and effective that the dropping of a wing could be counteracted with less trouble than on any other type. It also appeared that an error in the use of the controls near the inverted stall did not, as in the "Camel" and "Snipe," tend to induce an inverted spin.

S.E.5A.—Contrary to expectation the S.E.5A proved relatively amenable to the controls in inverted flight; its main difference from the unstable types lay in the position (about three-quarters way forward) in which the control stick had to be held to counteract its powerful self-righting properties. Scholefield found no difficulty in aileron technique to counteract a dropped wing, but was considerably puzzled by the use of aileron to carry out banked turns. As was explained previously, the bank necessary to produce an inverted turn is the reverse of that for a normal turn. Apart from this the controls had to be used as a whole more coarsely and vigorously on the S.E.5A, a feature that to some extent applies to its behaviour in normal flight. Although it was possible not only to fly the S.E.5A inverted, but even to stall it inverted, its self-righting properties were

such that, as far as investigation was able to show, no mishandling of the controls would result in the development of an inverted spin. If it be granted that the "Bat Bantam," with its extraordinary controllability, is an exception, the suppression of the risk of an involuntary inverted spin has generally to be paid for by a certain loss of ease in inverted manœuvres and by the extra force which is necessary to keep the nose of the aeroplane from falling.

Bulman found that, with tail adjustment two-thirds forward, he could stall the S.E.5A inverted at 70 m.p.h. Just prior to the stall it wobbled laterally, and frequently dropped the right wing. Though my experience relates to a different example of this type, I found that it was more often the left wing that dropped. In both cases the aeroplanes were, as far as the pilot could tell, in correct lateral trim. With the tail adjustment in the above position the aeroplane felt nose heavy both in normal and inverted flight; and although in the inverted stall the characteristics of instability were searched for, they could not be detected, being masked perhaps by the lack of elevator control. It is interesting here to note the difference between the S.E.5A and the modified "Camel," both of them longitudinally stable aeroplanes with powerful self-righting properties in inverted flight. The relatively long fuselage and effective elevator control of the S.E.5A enabled it to be stalled inverted in a similar way, apart from the greater control force necessary, to the unstable aeroplanes. The modified "Camel" had been made stable simply by a movement of its C.G. and without any modification to its tail organs except an appropriate alteration in tail setting. The control characteristics produced by its short fuselage and small tail, tolerable on a small highly unstable scout, became out of place when stability was secured, and spoilt the original unity of conception of the "Camel" design. Thus, although the modification to the "Camel" conduced towards greater safety in that its self-righting properties were enhanced, the pilot's control over it in certain attitudes of flight was reduced below what has been attained in the best example of a stable scout. The S.E.5A had even more powerful self-righting properties in inverted flight than the modified "Camel," and even then its elevator control was sufficient for it to be stalled inverted, whereas that of the modified "Camel" was not.

4 *Resuming Normal Flight*

(*a*) *General*

As for attaining the inverted position, there are two broad methods for resuming normal flight: by means of a half loop, or a half roll. The first method involves the loss of some height, say, a minimum of 300ft.; an average figure for height loss in the second method is 200ft.

To resume normal flight by means of a half loop, the pilot pulls the control stick towards him, and the aeroplane commences an inverted dive, from which it can be eased round to normal flight as in the end of a loop. But there the similarity to the second half of an ordinary loop ends. Two conditions account for this; firstly the control stick position, and secondly the speed. At the top of an ordinary loop the aeroplane is inverted, the control stick is fully back (as it is throughout nearly the whole loop) and the speed is very low, 40 to 50 m.p.h. At the commencement of the half-looping recovery from inverted flight the control stick is, depending on the stability characteristics, between just forward of the central position and fully forward, and the speed is between 70 and 75 m.p.h., slightly in excess of the inverted stalling speed. As mentioned later, the pilot has a considerable distance to pull the control stick back, during which movement the aeroplane is dropping its nose and tending to plunge into a high-speed inverted dive. Because the speed is greater than that at the top of an ordinary loop, the tendency in the recovery is for high speeds to be reached which hamper the backward movement of the control stick. The pilot therefore must handle the aeroplane gently but firmly. If he is at all uncertain in pulling the control stick back

it will gain speed in the inverted dive with great rapidity, and become harder, as explained above, to ease round and flatten out. If the aeroplane is flying quite slowly inverted, the pilot can afford, without stressing it unduly, to give a deliberate backward control stick movement calculated to swing it round to normal flight before it has gained an excessive speed. Once however it has been allowed to gain speed the pilot rightly feels that on the one hand he cannot make a sharp control movement for fear of stressing the aeroplane, and that on the other hand the gentler he is, the more will it continue to gather speed, and the longer will it take to come round.

Again, in using this method on a sensitive unstable aeroplane the pilot may find that the control stick comes back easily at first and then suddenly has a violent effect. It is necessary to feel for this carefully and damp an over violent elevator effect by easing the control stick slightly forward again. The behaviour of the aeroplane under these conditions constitutes a genuine difficulty in control, and to make a clean quick recovery the pilot has to seize his opportunity. To bring the aeroplane round in an even curve without letting it gain too much speed and lose unnecessary height, and yet without jerking it, needs, as can be seen from the above remarks, considerable care.

The other method of resuming normal flight is by means of the half roll. Whereas it is possible in most cases to attain the inverted position both by the slow and the quick half roll, to recover normal flight the pilot is compelled, except on an aeroplane like the "Bat Bantam" with its high manœuvrability, to use the slow half roll. In using the slow half roll experience shows that special care must be taken to harmonise the use of the controls with the stability characteristics of the type. On the more stable types, the best way to induce the half roll is to put on rudder in the desired sense of roll and push the control stick right forward (in any case to maintain inverted flight on these types the pilot will have the control stick well forward) and give aileron in the same sense as the rudder. As long as the aeroplane is inverted, the pilot cannot afford to pull the control stick back, for the self-righting tendency of the aeroplane will then be assisted by the elevator and the nose will drop immediately. With control stick forward and nearly full aileron and rudder the aeroplane should start to roll over. Then as it comes over the control stick is brought back; and the whole movement, allowing for the use of aileron, amounts to a circular sweep.

On a highly unstable aeroplane the pilot, in commencing the slow half roll, must be cautious in pushing the control stick forward; for if he pushes it right forward with rudder on, he sets up conditions favourable to the inverted spin. (See Part III. (1)). The further the control stick is pushed forward, the easier is the aeroplane to roll. While on unstable types the forward control stick position combined with rudder brings the pilot perilously near the inverted spin, these movements have consistently been employed with impunity by Bulman. My experience has been, however, that a reasonably good half roll can be induced by pushing forward the control stick slightly, putting on rudder, and giving aileron in the same sense. In many cases the aeroplane starts to roll out slowly and then suddenly develops a more violent motion that it is difficult to damp. This may be due to the fact that after the wings have passed the vertical the pilot is compelled to pull the control stick back to prevent the nose from dropping, and as speed has been lost in the course of the manœuvre, the aeroplane has become stalled, and auto-rotation has set in. If this happens, the pilot can only damp the motion by pushing the control stick forward again and finishing up with the nose down. On the other hand, if he keeps the control stick back, he overdoes the half roll, ends up with one wing badly dropped and is compelled to pull it up again, which is clumsy. The remedy can only lie in commencing the half roll from the inverted position with a sufficient margin of speed.

The pilot must find by experiment whether a particular aeroplane rolls out

more cleanly with the control stick relatively back or forward, the proportion of rudder to elevator that it is best to give, the correct synchronisation of the two controls, and the amount of aileron that eases the motion of the aeroplane. It is nearly impossible to recover normal flight by rolling without inducing sideslip. However sympathetically the controls are used no pilot has been able to avoid it, and a severe sideslip always means a certain height loss. In any case the slow half roll for recovery, though graceful to watch, always seems to the pilot somewhat of a compromise, and is, academically speaking, the least perfect of the manœuvres of inverted flight. As the quick half roll for recovery has only been performed on the " Bat Bantam," it is referred to in the notes on that aeroplane.

(*b*) *Application to Particular Aeroplanes*

Standard Sopwith " Camel."—To resume normal flight on the " Camel " by means of a half loop the pilot is compelled to lose some height, probably a minimum of 300ft. As explained before, he can make a quick recovery only by swinging the aeroplane round without allowing it to gather speed in an inverted dive. The " Camel " tends to go into this high speed inverted dive less easily than more heavily loaded or less unstable types. If, however, the inverted dive gains headway, the pilot may lose 1,000 to 2,000ft. before he has resumed normal flight. In my opinion it was the pilot's failure to appreciate the characteristics of this inverted dive that led to many accidents and concurrent reports that the controls were ineffective, or the elevator " blanketed." The aeroplane loses height so rapidly, and the elevator control feels so uneven in swinging the aeroplane round that it was natural for pilots to blame the control. The pilot has undoubtedly to learn what practically amounts to a trick in using the control; and if he is flying below 2,000ft. he may, if inexperienced, quite easily strike the ground in this inverted dive. The behaviour of the aeroplane appears inconsistent; under some conditions it may need a firm deliberate elevator movement and under others a series of gentle ones. The " Camel " itself is more likely to come round in a series of jerks than to plunge into the high-speed inverted dive. These jerks the pilot is inclined to check too violently, because in the various attitudes through which the aeroplane passes towards recovery the sensitivity of the elevator control varies, and he cannot easily foresee what effect his control movements are going to have. He may overdo the checking movements, in which case the aeroplane will start trying to re-invert itself, and he will lose a great deal of time and height in pulling it round to normal flight. In short, if the rapid low speed recovery is made, all is well; but if it fails, the pilot will meet difficulties that can only be overcome by practice (see Fig. V.).

An experienced pilot can resume normal flight by means of a slow half roll without losing more than 100 to 200ft. of height. He should not commence the manœuvre too near the inverted stalling speed; on the " Camel " a favourable speed is 80 m.p.h. He gives aileron and rudder in the desired sense of roll and pushes the control stick slightly forward. As mentioned before, Bulman was able to use a further forward position of the control stick than I was. Just after the wings have passed the vertical the pilot has to be careful with his rudder. Its use is determined by his effort to keep the nose of the aeroplane as far as possible in the direction in which the half roll was commenced. The aeroplane will inevitably sideslip and yaw slightly off its course. As soon as the wings are past the vertical the pilot can pull the control stick back to keep the nose up and gently or rapidly take off aileron, depending on how fast the aeroplane is coming round. If, however, he has lost too much speed, the aeroplane may swing round violently and the ailerons become useless. The motion can then be damped only by pushing the control stick forward again and allowing the nose to drop. To maintain an even rate of roll from start to finish the pilot must use good judgment in timing the control movements.

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Modified Sopwith "Camel."—During the recovery of normal flight by the half looping method, the modified "Camel," as was to be expected, behaved more like the "Bat Bantam" and S.E.5A than like the standard "Camel." As soon as the control stick is pulled back from the far forward position, the nose drops rapidly, and the pilot has to aim at swinging the aeroplane round before a high speed is attained. If he hesitates during his backward movement of the control stick, the modified "Camel" does not tend to re-invert itself; it simply gathers speed in the inverted dive.

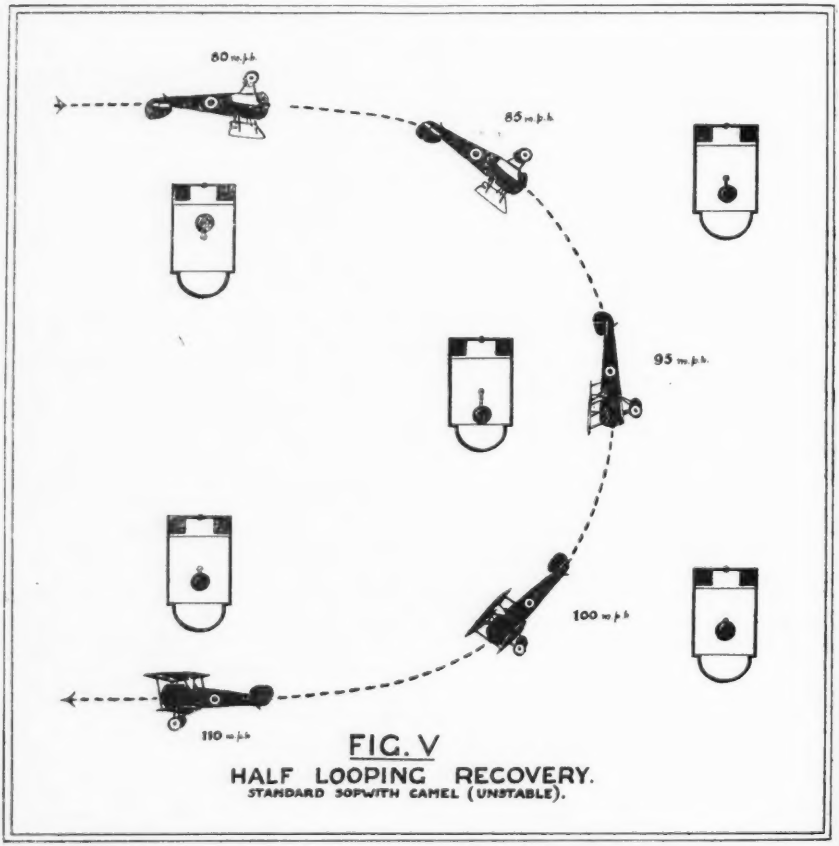


FIG. V
HALF LOOPING RECOVERY.
STANDARD SOPWITH CAMEL (UNSTABLE).

As this aeroplane shows no inclination to spin on its back, for the slow half rolling recovery the control stick may be kept well forward as rudder is given. Although some degree of sideslip and yaw are unavoidable, the manœuvre seems slightly easier to perform than on the standard "Camel," in that the timing and co-ordination of the controls need not be so delicate.

Sopwith "Snipe."—The control movements for the resumption of normal flight on the "Snipe" are similar to those on the "Camel." In the half looping method the "Snipe" shows the tendency to come round unevenly, and the same effort has to be made to achieve the rapid low speed recovery without jerking the

aeroplane. On the other hand the control stick must be brought back from just forward of the central position to full back before the speed becomes excessive.

The slow half roll for recovery presents the same problem as on the "Camel," and sideslipping is bound to occur. As the "Snipe" will go into an inverted spin with control stick right forward and rudder on, the pilot has to find for himself just how far forward he dare push the control stick to achieve the best roll without incurring the risk of an inverted spin. The similarity of the conditions favourable to the roll from the inverted position and the inverted spin is analogous to that of the conditions for the normal roll and the normal spin. This means that to attain favourable conditions for recovery by the half roll the pilot is bound to approach those for the inverted spin. It seems possible that he actually secures the conditions for the inverted spin and by some delicate economy of control movement which I have not been able to analyse, induces the half roll before the spin has scope to develop.

"Bat Bantam."—In the half looping recovery the "Bat Bantam" does not show the tendency of the "Camel" and "Snipe" to come round in jerks; it inclines rather to fall into the high-speed inverted dive. The pilot, with his control stick still further forward to maintain inverted flight, has a greater distance to pull it back to reach the correct position for swinging the aeroplane round. The "Bat Bantam," being heavily loaded, loses height very rapidly in the inverted dive, and it is particularly necessary to aim at the rapid low speed recovery.

The "Bat Bantam" does not tend with control stick forward and rudder on to fall into an inverted spin; and to induce the slow half roll for recovery the control stick may be pushed well forward. As with other aeroplanes, rudder and aileron are given in the desired sense of rotation. So effective are the controls that the half roll can be performed with an unusually small sideslip; in fact a quick half roll from the inverted position is also possible. The difference in control movement to induce the two kinds of roll seems to be one not so much of direction as of rapidity. To induce the quick half roll the control stick is pushed quickly forward, simultaneously with the application of rudder. A rapid whirling motion sets in, similar to that of the roll from normal flight; and once the aileron has been given to assist in starting the motion, it has little further effect. In the slow half roll, on the other hand, an alteration in aileron setting has an appreciable effect on the rate at which the aeroplane rolls over, and the pilot feels that he is flying the aeroplane round with the ailerons; in the quick half roll he has given aileron, stalled the aeroplane and allowed it to take charge.

S.E.5A.—During the half looping recovery the S.E.5A, in common with the "Bat Bantam," tends, if the pilot is not careful, to lose a considerable amount of height in the inverted dive. On the S.E.5A the pilot has the control stick further forward to maintain inverted flight than on an unstable or neutral aeroplane. The necessary backward movement of the control stick is therefore considerably greater, for in all the types investigated, the final position of the control stick for swinging the aeroplane round is fully back.

Although the slow roll for recovery, if skilfully performed, need only involve a comparatively small loss of height, the nose of the S.E.5A tends to drop so much that the pilot may lose as much as 700ft. in his initial efforts. When he is flying at low speeds inverted the control stick is nearly full forward. To commence the roll he pushes it along the dashboard to give aileron in the desired sense, and gives rudder in the usual way. As the wings pass the vertical the aeroplane will sideslip downwards, against its rudder. At this point the control stick must be pulled back along the side of the cockpit and, together with the rudder, finally centralised when the aeroplane has come round to normal flight. In unstable aeroplanes the corresponding control movement amounted to a circular sweep on one side of the cockpit; in the S.E.5A this sweep is elliptical, with its

major axis fore and aft of the aeroplane. The difference in movement arises from the necessity of using the elevator more coarsely. After the wings have passed the vertical the aeroplane, in addition to sideslipping, wants to yaw against the rudder. In the case of a right-hand half roll from the pilot's point of view, it yaws to the left, and *vice versa*. The tendency of the S.E.5A to yaw in the slow half roll for recovery seems more marked than in that for the attainment of the inverted position. Bulman suggests that when rolling into the inverted position, the pilot has the advantage of the engine with its consequent slipstream effect on the rudder until the last moment, whereas during recovery the slipstream effect is absent. If, by allowing the nose to drop, the pilot gains sufficient speed to compensate for this, the symmetry of the manœuvre is lost (see Fig. VI.).

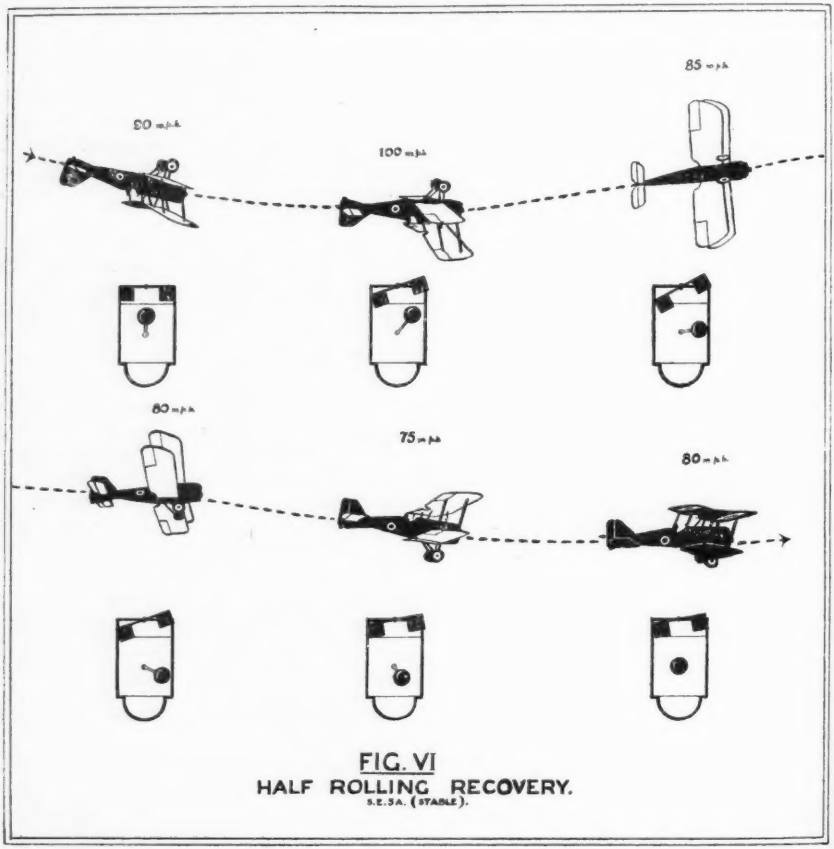


FIG. VI
HALF ROLLING RECOVERY.
S.E.5A. (STABLE).

5 *The Slow Roll*

This manœuvre is a synthesis of the slow half roll to attain the inverted position and the slow half roll for recovery. The two halves of the manœuvre should blend perfectly into a continuous whole. The control movements are therefore the same as those that have been described for the various aeroplanes in the attainment of, and recovery from, inverted flight. If an even rate of

roll can be maintained from start to finish, this manœuvre is undoubtedly the most graceful one at present known. Unlike the quick roll in which the control stick is kept well back the whole time, it cannot be associated in any way with auto-rotation. The fact that during the part of the manœuvre in which the aeroplane gradually approaches, passes through, and leaves the inverted position, the fuselage of the aeroplane remains approximately parallel with the ground, is due to the forward motion of the control stick which sets up conditions favourable to inverted flight. The rudder plays an important rôle, as distinct from the cardinal function of the elevator in setting up the stalled condition necessary to auto-rotation. Bulman felt that a more effective rudder would assist slow rolling, especially in handling the aeroplane during the awkward periods of side-slip. It was forcibly impressed on him in the following way:—The "Bat Bantam" was at one time rigged so that with the rudder bar central the rudder was offset to starboard. This meant that he had an increased range of rudder angle to port and a correspondingly decreased angle to starboard. He found that the extra rudder angle was of the greatest assistance in performing the slow roll to port. Altnough a rudder of larger area was at one time actually fitted to the "Bat Bantam," the rudder effectiveness, probably due to unfavourable gearing, was not sensibly increased.

PART III.—SPECIAL INVERTED MANŒUVRES

1 *The Inverted Spin*

The investigation of the inverted spin was in a sense the crux of the inverted flying experiments. Whether aeroplanes really did spin on their backs, and if so, what the actual condition was like, had long been a subject of controversy. If inverted spins occurred involuntarily, they should be capable of being reproduced intentionally, and described. If this could be done, one of the least appreciated and most discussed problems of flying would be exposed to analysis.

In reference to accidents on "A" the report of the Accidents Committee, R. & M. 617, states:—"Thirteen accidents in which inverted flight was a feature were examined. . . . The initial stage of the accidents varied, but in 10 out of 13 cases the aeroplane at some period spun on its back."

It was hoped that the inverted spinning associated with these accidents might be reproduced; that the problem of recovery might be solved; that the behaviour of the aeroplane prior to, during and subsequent to the inverted spin might be investigated to see if the control surfaces were sufficiently operative to make consistent and repeated recovery possible; and that a pilot with his brain clear might experience the physiological effects concurrent with inverted spinning.

During the summer of 1920 Bulman was making persistent efforts to reproduce the inverted spin on the Sopwith "Camel"; but, curiously enough, he was always unsuccessful for the reason shown later. In the following autumn Gerrard joined the R.A.E. and reported that in 1917 he performed the manœuvre unintentionally while commencing inverted flight on a Sopwith "Camel" with a standard non-shoulder strap belt. To attain the inverted position he held on to the seat with his left hand, half rolled and pushed the control stick forward (the correct movements). He forgot, however, to centralise the rudder when he became inverted, and went into an inverted spin with the engine off. He was thrown from his seat, still retaining hold with his left hand. To save himself from being thrown out further, his first effort was to grab hold of the seat with his right hand also. Being confused, he seized hold of the pressure pump handle instead, which partially broke away; in fact he nearly pulled it right out. By this time he was getting very low—about 800ft. from the ground—and with a final effort succeeded in reaching the control stick with his right hand, pulled it back and made a recovery just before striking the ground. He did not proceed further with inverted flying

until he had obtained and fitted a Curtis shoulder strap belt. Since then he had frequently carried out intentional inverted spins.

On joining the R.A.E. he explained to Bulman how the inverted spin was performed, and Bulman was able to go straight up and reproduce the manœuvre perfectly. The normal method of inducing a right-hand inverted spin from the pilot's point of view is to push the control stick fully forward into the left-hand corner of the cockpit and to give full right rudder, which means that rudder is given in the desired sense of rotation and aileron against it. For a left-hand inverted spin, the control movements are reversed. In the " Camels " previously flown by Gerrard the consequent motion of the aeroplane was as follows :—The aeroplane did a flat turn inverted, dropped its nose and commenced to spin on its back, in a somewhat similar way to a normal spin. Gerrard described the recovery as not essentially abnormal, except that the controls had to be used with the greatest gentleness to prevent the aeroplane coming out with a violent jerk, and that the height loss exceeded that in the recovery from the normal spin. It is best to check the spinning, in the case of a right-hand inverted spin, by moving the control stick across from the front left-hand corner of the cockpit towards the centre of the dashboard (taking off aileron), and by centralising the rudder gradually. The aeroplane may then be eased out of the resultant inverted dive by gently pulling the control stick back. In the case of a left-hand inverted spin, the control movements for recovery are made in the opposite sense. In a good recovery the height loss should not exceed that from a normal spin by more than 20 per cent. ; in a bad recovery it may run into thousands of feet (see Fig. VII.).

The " Camel " on which Bulman had been experimenting showed a strong tendency at low speeds to drop the right wing inverted [Part II. (3) (*b*)]. Gerrard flew it and considered that this tendency was more marked than in the " Camels " which he had previously flown. It was this individual peculiarity that seems to have confused Bulman in his initial attempts at inverted spinning. Gerrard found that when the control movements for the inverted spin were made this aeroplane, instead of flat turning on its back and sliding into a spin immediately, tended to drop the right wing and roll round the right way. If the controls were still held over, it rolled over again on to its back and commenced an inverted spin, by which time the nose had dropped to about 45 deg. with the horizontal. In attempting the inverted spin Bulman, finding that the aeroplane rolled round right away, immediately straightened it out in the belief that he had failed, and never guessed that if he persisted an inverted spin would result. Nevertheless when I tried the inverted spin on this aeroplane, in no case did I experience the tendency to roll out before the spin had commenced, which must have been due to a slight difference in handling the controls. Bulman lays emphasis on the extraordinary smoothness of the inverted spin. There is no suggestion of " kicking " round, a frequent feature of the normal spin on the " Camel." He also noticed that by taking off rudder slowly he could decrease the rate of rotation.

Although in my initial attempts at inverted flight on the Sopwith " Camel " I had several times mishandled the controls, it so happened that I had not, as a result, commenced an involuntary inverted spin. As I was anxious to gain experience of the manœuvre I carried out a considerable number of inverted spins. I judged that it would be a matter of considerable difficulty to read instruments in this condition; in any case I was compelled to concentrate on reading one at a time. In ordinary inverted flying it is possible to read even two or three instruments at once. Having previously shut off the engine and petrol, I commenced inverted spinning by half rolling gently on to my back at 5,000ft., and producing an inverted glide. I steadied the airspeed to 80 m.p.h. and then gently eased the control stick forward and to my left, and gave full right rudder. The aeroplane showed no hesitation in answering. It did a flat turn

to the right, and started spinning inverted with the nose fairly well down, in a roughly similar attitude, except for the inversion, to that of a normal spin.

I agree with Bulman that the inverted spin is unlike the characteristic "Camel" spin; it seems both smoother and slower, and there is no "kicking" noticeable. As soon as the spin commenced I felt the negative acceleration increase, and the belt stretched a little. I was able, however, to read the airspeed, which settled down to 90 m.p.h. The pitot head is mounted on the starboard wing strut, which would be the inner one in the spin. Its reading in an inverted spin would probably be subject to a considerable correction.

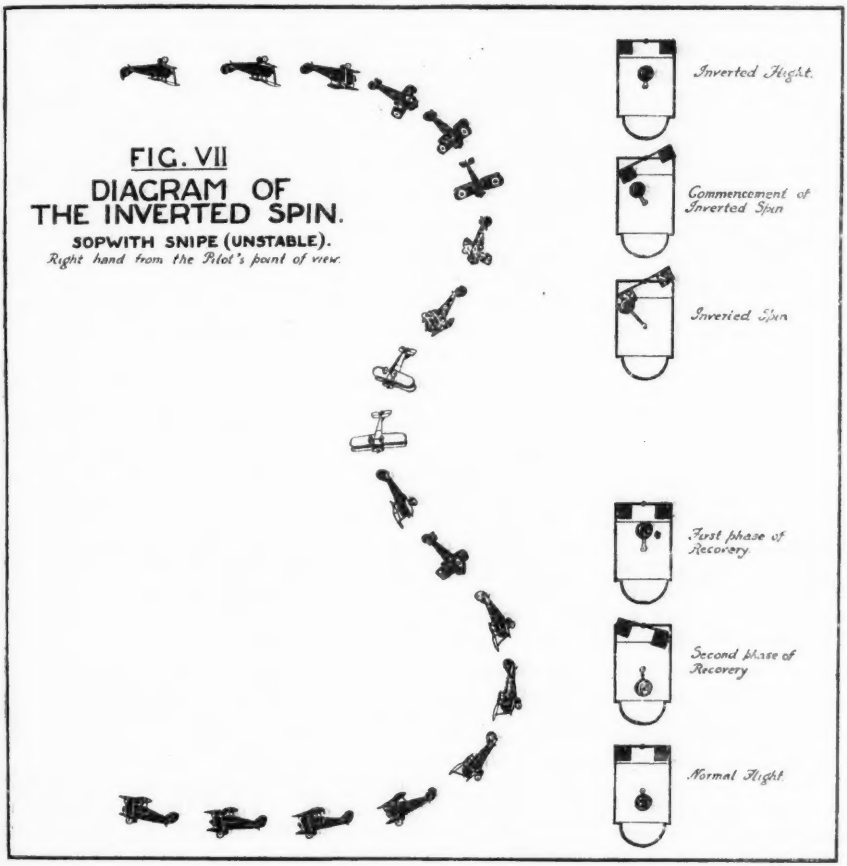


FIG. VII
DIAGRAM OF THE INVERTED SPIN.
SOPWITH SNIPE (UNSTABLE).
Right hand from the Pilot's point of view.

After spinning for 1,500ft. I gently eased the control stick towards the centre of the dashboard and then backwards, simultaneously centralising the rudder. After what seemed like one to one and a half turns the rotation slowed up, started again momentarily, and then ceased; after which I emerged in an inverted dive. In this dive I attained a considerable speed, over 160 m.p.h., being reluctant to handle the aeroplane roughly and flatten out too violently. This procedure, however, involved the sacrifice of about 1,500ft. of height, and my nose crosses the

horizon at 2,000ft. Just as in the half-looping recovery from the inverted position, the speed in the inverted dive tends to rise very rapidly, and it is essential always to aim at the low speed recovery. In such dives I have more than once attained speeds in the neighbourhood of 200 m.p.h. During the inverted spin proper the pilot, though subject to violent negative acceleration, is quite able to realise where he is and visualise his attitude; during the recovery and consequent reversal of the sign of apparent gravity, he tends to feel dizzy for a few moments.

One of the most important things to discover about the inverted spin was at least an approximate notion of the loads imposed on the wings, and hence the margin of strength. I was therefore anxious if possible to measure the acceleration in the spin, and had a simple type of spring accelerometer (non-recording) fitted between the guns so that it was close to my face and easy to read. This accelerometer was used by Lindeman in his early spinning experiments. I commenced inverted spinning at 5,000ft. in the same way as before. The indicator of the accelerometer appeared to rise steadily but quickly to $-2G$, and to remain there for as long as I was able to watch it. At about 3,500ft. I had intended to make the control movements for recovery. I was, however, beginning to be confused, and think that while centralising the rudder I may have kept the control stick forward or have failed to pull it back enough. When I next appreciated what was happening I was gliding fast on my back at about 120 m.p.h., side-slipping with my right wing down. It took me a few moments to decide whether I was inverted or not, as, having been subjected to large unusual accelerations, my sense of feel seemed partially paralysed. On realising the position I gently eased the aeroplane into an inverted dive and recovered normal flight at just under 2,000ft. I subsequently read the accelerometer in a straight inverted glide, and its reading was approximately $-1G$.

Up to that time it had been an open question whether it was possible to pass direct from an inverted spin to inverted flight, the normal recovery being an inverted dive. That I did so unintentionally proves the possibility of it; indeed the manœuvre virtually amounts to the first phase of an inverted loop. It was unfortunate that I was unable to control myself sufficiently during this period to read the accelerometer, as the reading should have been of interest. The fact that I passed direct into the inverted position in trying to recover from an inverted spin, seems to point to the persistence of habit formed during normal spinning, the recovery from which requires the control stick forward. Although I had clearly thought out the whole manœuvre beforehand, yet when the time came for recovery I failed to make the subconscious effort to pull the control stick back.

I carried out another right hand inverted spin and was able to watch the spring accelerometer more carefully. During the spin the indicator oscillated between -1.8 and -2.2 G., the period of the oscillation being approximately in phase with the rotation of the aeroplane. Bulman then carried out two left hand inverted spins and observed a similar oscillation between -1.6 and -2.4 G. Later on a recording accelerometer was fitted up and a record that I obtained in a right hand inverted spin is shown diagrammatically in Fig. VIII. For purposes of comparison a record of a straight inverted glide is shown in Fig. IX. The maximum force on the wings during the inverted spin is seen to be -1.7 G., a figure lower than that obtained from the non-recording spring accelerometer. Taking into account the conditions under which the latter had to be observed by the pilot, great reliance cannot be placed on the readings taken from it.

It was possible to induce an inverted spin on the modified "Camel" by the same class of control movement as that for the standard "Camel." The controls, however, especially the elevator, had to be used more vigorously to prevent the nose from dropping before the rudder came fully into play. The inverted spin felt similar to that on the standard "Camel" except that the rotation seemed

FIG. VIII

INVERTED SPIN

STANDARD SOPWITH CAMEL. ENGINE SWITCHED OFF.

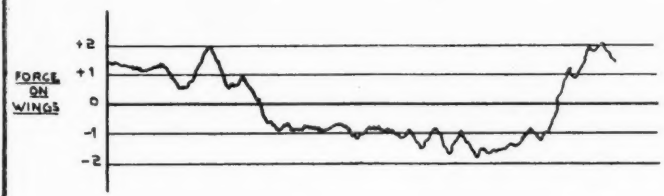
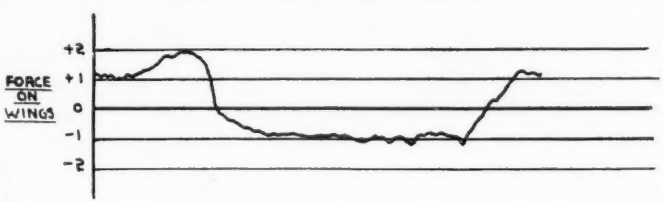


FIG. IX

INVERTED GLIDE.

STANDARD SOPWITH CAMEL. ENGINE SWITCHED OFF



NOTE. These diagrams were copied from Accelerometer records

faster and the recovery more certain. When the controls were set for recovery, instead of answering sluggishly, the aeroplane answered immediately.

Gerrard reported that he had carried out inverted spins on the Sopwith "Snipe," and that the smoothness remarked in the standard "Camel" was a feature. The control movements for entry and recovery were similar to those that have been described for the "Camel." It is also known that the "Snipe," if mishandled, shows a tendency to fall into an inverted spin in the same way as the standard "Camel."

Considering the abnormal behaviour of the "Bat Bantam" in an ordinary spin, the greatest caution would have been necessary in attempting the inverted spin. All that was actually established was its reluctance to fall into an inverted spin near the inverted stall, in which respect it behaved in a similar way to the more stable aeroplanes. There is, however, no doubt that it was fully capable of inverted spinning, had the manœuvre been deliberately attempted.

Finally I tried an inverted spin on the S.E.5A. I set the adjustable tail at its maximum incidence, thus producing considerable nose heaviness in normal flight. I made the usual control movements and the aeroplane entered an inverted spin in much the same way as the modified "Camel." The rate of spin was less smooth, with a noticeable "kick." The S.E.5A showed no tendency to fall into the inverted spin; in fact the pilot had to be determined with the controls to produce it at all. Once produced it was, in spite of the "kicking," perfectly definite and consistent. The recovery was more direct than on any other of the aeroplanes examined.

The conditions favourable to the inverted spin required that rudder should be applied when the control stick was in a far forward position, or conversely that the control stick should be pushed forward when the rudder was across. When carried out intentionally, the inverted spin had always been produced with control stick forward, rudder given in the desired sense of rotation and aileron against it, by analogy with the normal spin. In normal spinning, however, it has been found that the ailerons are the least important factor in exciting or governing the motion, and that aeroplanes can readily be spun with ailerons neutral or given in instead of against the desired sense of rotation. It seemed natural that this should be true of the inverted spin. I therefore made tests on the standard "Camel" to investigate the influence of aileron. I first tried to induce an inverted spin by flying inverted, pushing the control stick forward without giving aileron and applying full rudder. The "Camel" did not appear to respond quite as readily as with aileron given against the sense of rotation, but fell into an inverted spin for about a turn and a half, threw itself violently out and began to gather speed. I then tried again by inducing an inverted spin with aileron against the sense of rotation and slowly moving the ailerons during the spin until they were fully over in the same sense as the rotation. The spin slowed up slightly and became less even, but still persisted until I made the movements for recovery. These tests showed that for inverted spinning the position of the elevators and rudder was more important than that of the ailerons. This point has a distinct bearing on the chances of falling into an involuntary inverted spin by a mishandling of the controls.

It will be seen that the pilot, when attaining the inverted position or resuming normal flight must, with aeroplanes showing a natural tendency to spin inverted, be cautious in approximating to the conditions favourable to the inverted spin. In no manœuvre to attain inversion or to recover from it does the pilot need to have the control stick forward with rudder and ailerons "crossed"; but in attaining inversion by the half looping method there is just the possibility of an overlap of full rudder with control stick right forward and ailerons neutral, and in attaining inversion or recovering from it by the half rolling method the control

stick may be right forward with aileron given in the same sense as the rudder. It is clear that although aileron against the rudder is apparently the most favourable to inverted spinning, so long as the control stick is forward with rudder across, the conditions essential to inverted spinning are, in highly unstable aeroplanes, satisfied. As was mentioned in Part II., the more unstable the aeroplane the more careful will the pilot have to be. On the other hand, with aeroplanes that are neutral or stable he will probably experience no difficulty and be able with impunity to push the control stick right forward with rudder full across. If he finds it possible he should use this elevator-rudder combination unhesitatingly, as it is a powerful weapon for inducing good half rolls from or into the inverted position.

The physiological effects of the inverted spin do not seem to be at any one moment as severe as those of the inverted half loop (Part III. (2)), although the pilot is tending to be thrown from his seat and naturally feels the rush of blood to his head. These effects are nevertheless longer sustained and appear to be harder on his physique mainly because, although the force of apparent gravity may be no greater, the reversal of its sign produces a very unnatural sensation. The most violent reaction occurs neither during the inverted spin nor at the period of transition from the inverted spin to the inverted dive; it occurs when the pilot is flattening out from the inverted dive, presumably during an acceleration in which the force of apparent gravity is positive. As the pilot has been subjected to forces of the opposite sign, the reaction due to such an acceleration, even though of moderate intensity, is unusually severe. A frequent effect on the pilot is that for a moment or two everything goes black; but the sensation is accompanied by no pain.

The inverted spinning experiments proved definitely that recovery from an inverted spin is not inhibited by ineffectiveness of the elevator or rudder; and that spinning can be checked by centralising the controls, after which the aeroplane can be gently eased out of the resultant inverted dive by a backward movement of the control stick. This points to the conclusion that pilots who failed to recover either were prevented from making any consistent and reasoned control movements by a physical condition induced by the accelerations of the aeroplane, or fell out of their seats due to inadequate belting arrangements, and were unable to reach the controls. If they could have steadily held the controls anywhere near their central position, spinning would have ceased, and a gentle pull on the control stick would have righted them. The utter confusion of an inexperienced pilot when spinning inverted is not, however, difficult to imagine, especially when, even assuming he were held to his seat, he had no idea of the requisite control movements. Such a pilot, subjected to the onset of violent accelerations, would be unlikely to hold the controls central; unless he had by systematic mental drill been definitely taught what it was necessary to do to recover from such abnormal conditions, he would probably make wild coarse control movements; and, as if this were not enough, the control movement (pushing the control stick right forward) that ensures recovery from a normal spin is the very movement that induces and maintains the inverted spin. Hence the danger.

2 *Possibilities of the Inverted Loop*

Bulman and Sainsbury experimented on the "Bat Bantam" to investigate the possibility of carrying out a complete inverted loop. I believe that Pégoud performed the first half of an inverted loop in 1912 on a Blériot monoplane, but that since then the manœuvre had received no serious attention. For these experiments the pilots strapped themselves in so tightly with shoulder strap belts that the discomfort would have been too severe for a flight of long duration.

XUM

Sainsbury also made use of the fairing behind him, under which he was able to wedge his shoulders.

By the term " inverted loop " is meant a loop in which the undercarriage of the aeroplane is inside the loop, that is towards the centre, and in which the loads on the aeroplane are the reverse of a normal loop. When the aeroplane became inverted the engine (a Wasp Radial) ceased to fire almost immediately. Bulman and Sainsbury first tried to estimate the speed that would be required for the performance of an inverted loop. They noted the fluctuation of speed during a normal loop commenced at 100 m.p.h. with engine on, and the speed at the top of the loop was observed to be 55 m.p.h. With a fast loop commencing at 120 m.p.h. a minimum speed of 60 m.p.h. was noted. Secondly, the stalling speed of the aeroplane when inverted was examined and found to be approximately 73 m.p.h. While the lateral control when inverted was quite satisfactory above speeds of 80 m.p.h., below that speed it became sloppy and was soon followed by the longitudinal control. Comparing the stalling speed of the " Bat Bantam " inverted (73 m.p.h.) to its stalling speed in normal flight of approximately 52 m.p.h. the inefficiency of the wings in inverted flight was apparent. This speed of 73 m.p.h. would have to be exceeded during the critical period of the inverted loop.

Bulman and Sainsbury next attempted to perform the second half of the inverted loop. In order to do this it was necessary to start from the inverted position. The " Bat Bantam " was flown inverted at as high a speed as possible without inducing too much of an inverted dive, on parallel lines with the dive sometimes made to gain speed for a normal loop. A favourable commencing speed in inverted flight proved to be 130 m.p.h. When the pilot had attained this speed on his back he pushed the control stick fully forward; the aeroplane recovered a little height, but lost speed rapidly and nearly stalled, the speed having fallen to about 75 m.p.h. This was tried a number of times, but in no case did the aeroplane make a serious attempt at completing the second half of the inverted loop (see Fig. X.). Attempts were then made to perform the complete inverted loop by pushing the control stick forward when the aeroplane was in normal flight. The commencing speed varied from 50 m.p.h. to 130 m.p.h., both with engine throttled down and full out. In each case the aeroplane passed the vertical and completed an inverted half loop; but with the control stick kept fully forward the aeroplane, instead of continuing round, lost speed very rapidly, stalled and the engine ceased to fire. Except for a more rapid loss of speed, its behaviour was exactly similar to that described in the previous experiments in which the second half of the inverted loop only was attempted (see Fig. XI.). The speed at which the inverted loop was commenced did not appear to make much difference, as at high speeds the pilot did not dare to use the controls violently for fear of stressing the aeroplane unduly, and increasing the already large force tending to break his belt and throw him from his seat.

It is possible that had special arrangements been made to enable the engine to run inverted, the aeroplane might have been made to complete the inverted loop. Considering, however, the heavy stressing to which the aeroplane had inevitably to be subjected during this manœuvre, the experiments were not pushed further. Whereas a maximum force of -1.7G was obtained for an inverted spin, it is possible that the force on the wings during an inverted loop might reach a considerably higher figure.

I made one attempt with the spring accelerometer to measure the acceleration during the first half of the inverted loop on a Sopwith " Camel." I produced the manœuvre in the most gentle way possible, by stalling the aeroplane sharply in normal flight, allowing the nose to drop and pushing the control stick quickly forward, thereby hoping to swing the aeroplane round before the speed rose excessively. This I was successful in doing, but was unfortunately unable to

ATTEMPTS AT INVERTED LOOPING
BAT BANTAM AEROPLANE

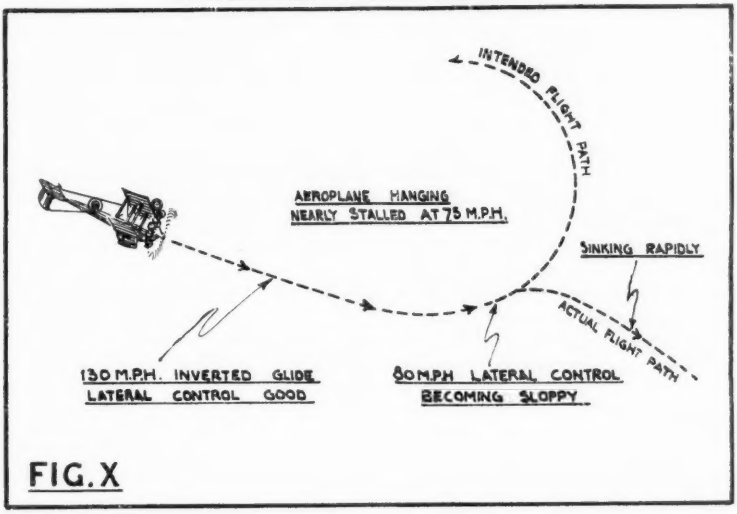


FIG. X

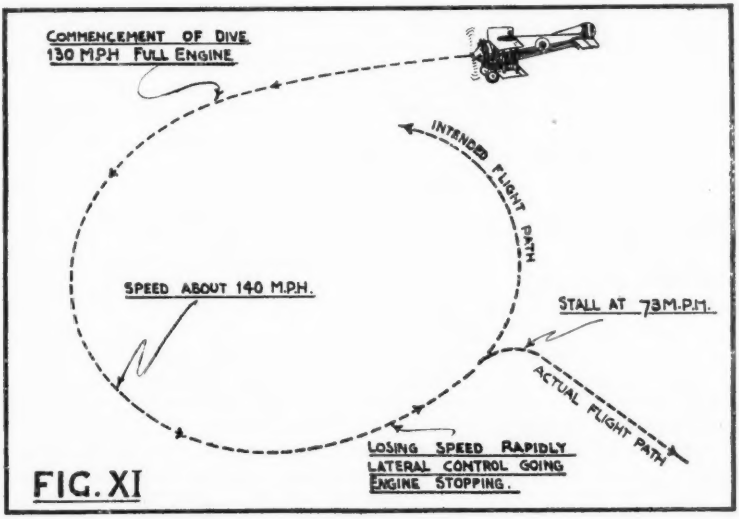


FIG. XI

keep my eyes on the accelerometer, and so failed to obtain a reading. Incidentally I must have applied rudder as I approached the inverted position, for the aeroplane fell sharply into an inverted spin.

The first half of an inverted loop can be regarded as yet another method of attaining the inverted position; as, however, it contains special features of interest, I have treated it separately. Although in the second half of an inverted loop, even could it be performed, it is difficult to see any military value, in the first half there are undoubted possibilities. In combination with a half roll it could be utilised for a rapid change of direction. The pilot would be flying in one direction, perform an inverted half loop, fly for a moment inverted and then half roll out flying in the reverse direction. This manœuvre would actually seem a more rapid way of reversing the direction of flight than that of turning with a vertical bank. In aerial combat, the attack is often made in a steep dive. Almost as often it happens that the pilot of the diving aeroplane is compelled to cease firing because his opponent's aeroplane, flying in the opposite direction, passes underneath him. If the attacking pilot could continue into an inverted dive, still firing, pass into the inverted position and half roll out, he would find himself flying behind his opponent's tail and in the same direction, with further favourable opportunities of attack. The possibilities of the inverted half loop remain to be proved; but it is certain that a fighting scout, capable of performing any given manœuvre and designed for war, will bring with it the pilot determined to explore its value as a weapon of offence. It is therefore essential that the designer, breaking away from present-day tradition, shall foresee future developments in aerobatics, and as far as possible allow for them in the strength of the design.

3 *Conclusions*

(*a*) That the belting arrangements of any fighting scout, more especially an unstable one, are of supreme importance. So far as I know, a belt has not yet been evolved which simultaneously fulfils the three necessary requirements—firstly, that of holding the pilot securely in his seat during inverted manœuvre; secondly, that of giving him the freedom to look round over his tail that the proper management of a single-seater fighting scout requires; and thirdly, that of transmitting the shock of a crash to his body in the manner least calculated, under the circumstances, to injure it.

(*b*) That on all the types of aeroplane open to investigation it was possible to maintain steady inverted flight. The chief difference lay in the absence of self-righting properties in the longitudinally unstable type, and the presence of powerful self-righting properties in the longitudinally stable type. To maintain inverted flight on the different types a marked difference in control stick position was evident. Though if anything more longitudinally stable than the modified "Camel," the S.E.5A was the more controllable aeroplane in inverted flight because of its effective tail.

(*c*) That there is no tendency for an unstable aeroplane to remain inverted in the sense that an experienced pilot has any real difficulty in recovering from the inversion. Recovery is prevented by inability to reach the controls due to inadequate belting, by confusion in handling them, or by an insufficient margin of height. With a knowledge of how to use it the pilot has control sufficient for ultimate recovery from all attitudes of flight. The least favourable condition is that of the high-speed inverted dive. Time and height are then necessary for recovery. Though it is suggested that the standard Sopwith "Camel" may be stable inverted, it is a fact that no control forces of any magnitude are requisite to overcome the effect of this stability.

(*d*) That whereas on all types of small scout can inverted spinning be performed intentionally, the longitudinally unstable type only is liable, if mishandled

during inversion or recovery from inversion, to fall into an involuntary inverted spin; that provided the pilot appreciates the correct control movements to make, recovery from the inverted spin presents no insurmountable difficulties; that an error in making the correct control movements for recovery leads to the loss of a far greater interval of height than in the case of a normal spin; that a minimum of 1,500ft. should be allowed for recovery, instead of the usual 400 to 600ft. for a normal spin; and that even 1,500ft. is a narrow margin if the possible physiological effects on the pilot are taken into consideration.

(*e*) That so long as there existed a school of thought which held that longitudinal instability was an inalienable accompaniment of good longitudinal control it was natural that this instability should be tolerated as a necessary evil; that the foregoing experiments indicate that all the manœuvres of inverted flight, excepting perhaps the inverted half loop, can be satisfactorily performed on a highly stable aeroplane, provided that its control organs are well designed; that the best compromise between safety and extreme manœuvrability is to be found in an aeroplane which, though preferably stable throughout the major part of its range of flying speeds with elevators free, must definitely be stable with them fixed.

(*f*) That judging by the steady rise in the standard of aerobatic performance required of the scout pilot, it is evident that this standard will not only be maintained, but rise yet higher; at least higher in the sense that what the experienced and matured pilot does to-day, the novice does to-morrow; that the manœuvres of inverted flight will take a prominent place in the curriculum of every flying training school; that because in peace time they train the pilot's judgment, make his hand sensitive, stiffen his nerve, they will adequately prepare him for the more serious issues that every service pilot may one day have to face; and that the above contentions are a wholly reasonable answer to the question, if it should be asked: "What is the use of inverted flying?"

(*g*) That in the design of a fighting single-seater aeroplane, specific account should be taken of inverted manœuvre. Because in the manœuvres contemplated when the aeroplanes that exist to-day were designed, this was hardly more than an incidental possibility, there is a widespread lack of confidence in their margin of strength against the loads imposed during inversion. Even were such anxiety ultimately to be proved ill-founded, its very existence justifies an adequate study of the manœuvres of which in time to come a fighting aeroplane may be capable, and its practical application to stress calculation of the future.

The CHAIRMAN, before opening the discussion, said he could not help thinking that everybody present must wonder which of the three or four outstanding qualities of Squadron Leader Hill was the most remarkable—as a pilot, as an observer of flying manœuvres, as a writer or as an orator. He believed that Squadron Leader Hill would gain most satisfaction from his capacity as an observer than from either of the others, but there was no doubt that anyone who heard him speak on this extremely interesting subject—one which was not exactly incomprehensible, but was very difficult to follow without a lot of experience—would wonder at his clear mind. Generally speaking, pilots were extremely good as observers, and it was only when they plunged into design and tried to alter their aeroplanes themselves that they broke down. As observers, it was perfectly extraordinary how pilots could follow out what they did and what happened in an aeroplane during the most complicated manœuvres. As far as he himself was concerned, he had never attempted any such feats and manœuvres as those so simply talked about by Squadron Leader Hill. On one occasion he had gone up in order to observe some particular phenomenon which had been bothering himself and others, and which involved the machine in a spin, but he was sorry to say that he was unable to give any clear account of what did happen. (Laughter.)

XUM

Continuing, he said he did not know whether everybody was aware of the origin of the paper which Squadron Leader Hill had presented. It was written, in the first place, for the Aeronautical Research Committee, but it had struck everybody on the Committee as being so excellent for general publication that permission was obtained to have it presented to the Royal Aeronautical Society. There could be no possible doubt that publication of the story of this work could do nothing but great good, by the simplification, for the benefit of pilots, of all the various manœuvres and difficulties which were still standing in the way of flying. He could remember quite well the time when "stalling" was entirely misunderstood; all that was known was that the machine would fall to the ground, as people said, without any apparent reason at all. Gradually these difficulties that pilots experienced were being cleared away and simplified. It was by the experiments made by Squadron Leader Hill and his staff of experimental pilots that almost the last obstacle was cleared. A very small amount of public thanks or reward came to these men, but he could not help thinking that there was amongst themselves a feeling of great satisfaction in the knowledge that what they had done would be of great use in the future. Finally, the Chairman asked anyone who had any remarks to make—and he saw one, if not two, of the pilots who had taken part in the work, present—to say something about his experiences.

Discussion

Wing-Commander T. R. Cave-Browne-Cave, in opening the discussion, said that, unfortunately, he could not contribute anything to it from his own personal experience. This investigation was a remarkably complete one of a very difficult problem, and the solution which Squadron Leader Hill had presented showed exactly in what the difficulty lay. There was no serious trouble in getting out of the inverted position, or in controling one's machine whilst in the inverted position, provided one knew what to do and could also think clearly. The value of the investigation was that the way in which the result was presented was so clear that it should be possible for pilots to keep their minds clear and to remember exactly what they had to do if they got into the inverted position unexpectedly. He admitted that it was difficult to think clearly under these conditions, but if it could be done, then, apparently, there was no real difficulty. The diagrams which Squadron Leader Hill had shown, he considered excellent. They were most important, and he considered that the value of the lecture would be prejudiced seriously if they were not reproduced in the journal.

The lecturer had referred to "left" and "right" wings, and "left" and "right" rudder, as distinct from "port" and "starboard." "Port" and "starboard" were accepted terms, both in the Air Force and in the "Engineering Standards Glossary." An advantage of using them in this respect was that if one spoke of "port" and "starboard" they obviously referred to terms as appreciated by the pilot. If one saw a ship in the distance turning to port, one always described it as turning to port, as seen by the Captain of the ship, however it might appear to the speaker. The terms "port" and "starboard," being somewhat more formal than left and right, would make it clear that one was using what was obviously the only logical system of terms, *i.e.*, the terms as appreciated by the pilot himself. "Up" and "down," he admitted, were a little more difficult, but it would be wise to adopt the terms "port" and "starboard."

There was one point mentioned by the Chairman, which he wished strongly to support, namely, the thoroughness of this investigation. The actual flying work, he believed everyone would agree, was "a brave business," but Pegoud, for instance, had done that when aeroplanes were in a very much more primitive form than they are to-day. What had struck him about the present investigation was that it was scientifically carried out and very carefully observed. The deductions were correctly drawn from the observed facts, and had been presented by

Squadron Leader Hill in a very full and extremely clear paper, which finished up with the conclusions which he and the pilots who had worked with him had drawn from them—a very important feature—and a guide as to what work should be done next. As a complete investigation of a very difficult problem, this must be taken as a model.

Flight Lieutenant T. E. B Howe, referring to the lecturer's statement that, in the design of the new fighters, specific account would be taken of stresses due to inverted manœuvre, asked whether the present machines, such as the Sopwith "Snipe," were suitable for practising inverted flying which many of those present would be encouraged to do as the result of the lecture.

The Chairman said that he did not think there was much doubt that the Sopwith "Snipe" had plenty of strength for ordinary upside-down flying.

Flight Lieutenant Howe said that he had noticed that the landing wires were not so strong as the flying wires; and that, in the accelerometer diagram shown by the lecturer, the stresses of an inverted spin were shown as —2.

The Chairman replied that the safety factor of a "Snipe" was 5—6, and he should think, when flying upside down, it would be about 4.

Flight Lieutenant Howe said he would like to know whether the present fighters were suitable for inexperienced pilots to practise inverted flying.

This question the Chairman was not prepared to answer. But in his closing remarks the Lecturer made it clear that he thought it better to try these manœuvres intentionally rather than to be unprepared for a possible unexpected experience of that sort.

Flight Lieutenant Bulman said he was rather of the opinion that Squadron Leader Hill would come in for severe censure by that large and influential body, the Pilots' Union; all their stock in trade had been given away, and nothing was left secret. (Laughter.) Coming to more serious things, however, he asked if one realised the difficulties which Squadron Leader Hill had in co-relating the various reports from the pilots who had tried some of these inverted flights. Nearly all pilots had different ideas, and expressed them in different ways, and it was not until some of them tried to practise some of these manœuvres in formation that they really understood the difference in their methods of performing what was apparently the same manœuvre. Taking, for example, the apparently simple half roll to attain the inverted position, he remembered that the first time they tried this together they were in "line ahead," and thought it would be quite easy, because the man behind could just follow the man in front of him. However, the slowing up of the first machine as soon as it started the manœuvre was extraordinary, so much so that the second man simply dare not attempt to perform the turning over, for fear of running into the man ahead. That was quite a fallacy, however, because he in turn also slowed up, but it certainly seemed almost impossible to avoid hitting the man in front. Then there was the question of the lateral displacement during the half roll. From the ground observer's point of view the wings appeared to turn about the longitudinal axis of the machine. Actually the aeroplane rotated about a point outside its wing tip and finished the manœuvre on a course parallel to its original flight path, but some 20 or 30 yards to one side of it. The inefficiency of the aeroplane when inverted was also very marked when flying in formation. A pilot, fearing he was getting below the machine in front of him, would push his stick forward. Instead of the aeroplane rising it actually descended more rapidly unless the air speed were 20 m.p.h. or so above the stalling speed inverted.

Captain G. T. R. Hill said he could not speak from any extended personal experience of upside-down flying. The only occasions on which he had indulged in it were when his machine had become inverted by mistake, and then it only lasted

for a very few seconds, because he had always rectified matters as speedily as possible.

What had struck him in the paper, apart from the sections dealing with the technique of flying upside-down, was the relation, which was insisted upon again and again, of the power of the controls to the stability of the machine. They had heard described the case of one aeroplane that was stable, and the controls had a certain effect, while another aeroplane, which was unstable, was contrasted with it, and the controls had an entirely different effect; this difference was much more than one might have expected, judging by the relative sizes and areas of the control surfaces. That seemed to bring out one of the great difficulties in trying to judge the effectiveness of the control by examining the data which is available in the greatest quantity, namely, that from the wind channel. In most cases these data were obtained from happenings in an aeroplane situated at one point, at a steady speed, whereas in an actual manœuvre the conditions were changing continuously, and at present, when we wanted to think about control, we had only very limited data with a direct bearing on the problem at our disposal. Even these data did not lead us very far, and this paper by Squadron Leader Hill had made a great addition to our knowledge in this direction.

He had been carrying out some preliminary experiments on the measurement of control, and, although he had only just started, some of his results had confirmed by actual measurement one of the statements made by Squadron Leader Hill—which is now really a generally accepted phenomenon—that in the stalling of an unstable aeroplane when the nose was pulled slowly up, the speed would drop off, and it would hang for quite a long time before putting its nose down, in contradistinction to the behaviour of a stable aeroplane, which stalled and put its nose down comparatively quickly. Some of the records he had obtained on his Bristol Fighter, which was unstable, showed that when the aeroplane was stalled quite slowly it would hang for several seconds, the nose, perhaps, falling by only two or three degrees, which was hardly noticeable, before it really puts its nose right down, and that behaviour, he saw from the paper, was attributed to the S.E.5 when flying upside-down. When the S.E.5 was right way up it was stable and would stall suddenly, but when upside-down it was unstable and stalled gradually. Although two aeroplanes of the same size of controlling surfaces, to all appearances, might at first sight be expected to behave in the same way, the question of the stability did influence the behaviour a great deal. The paper emphasised that again and again, and he considered that it should be thoroughly absorbed by all people who had to deal with the problem of control.

The overpowering effect of the stability, or the "aeroplane's own will," over the control by the pilot led, obviously, to a state of danger. Supposing we could ensure that the control was so effective that the pilot could always overcome whatever the aeroplane wanted to do, we should be in a much happier state than we are now. At the present time, a pilot of an ordinary machine, going up to try these curious and harassing manœuvres, might be likened to a child leading out a fierce wolf-dog for a walk. Things perhaps, one day, went wrong, the dog pulled the child over, and very likely turned and gobbled him up. What was wanted was the aeronautical equivalent, if he might say so without disrespect, of their Chairman exercising his pug dog.

Squadron Leader HILL, replying to the discussion, said that all the speakers had been very kind to him, and there was very little for him to do except to thank them. In reference to the remarks of Wing-Commander Cave-Browne-Cave, he would certainly try to get the diagrams illustrating the lecture; he believed that they were at the R.A.E. He was inclined to agree with the advisability of using the terms "port" and "starboard," and considered that it would possibly bring the terminology into better line. He wanted to make it clear that the pilot must

refer to control either from his own point of view or, at any rate, from some consistent point of view.

Wing Commander CAVE-BROWNE-CAVE said it was necessary that the terms used should be in reference to the position of the pilot.

Squadron Leader HILL suggested that difficulty as to terms of reference might arise if two aeroplanes were flying together and one was inverted while the other was right way up.

Wing Commander CAVE-BROWNE-CAVE considered that, when speaking of what a pilot was doing, it was very difficult to make a case for using anything but the terms that he appreciated.

Squadron Leader HILL said he thought the suggestion was a right and proper one. With regard to the stresses in inverted manœuvres, perhaps he had not made himself quite clear. He had not suggested that the present aeroplanes were not strong enough for inverted flight, but merely that the extent of their margin of safety was less certain than that for normal flight. The point he wished to emphasise was that it would be a good thing, now that we have some data on inverted flight, if the stressing were looked at from the point of view of inverted manœuvre, to see if it could be improved. As we got to know more and more about aeronautical engineering, aeroplanes constantly improved; but there was never a time, even in the early days, when a pilot was not prepared to try any manœuvre if he thought it could be done. He did not mean to say they did absolutely mad things; they flew to the best of their ability, but did not allow possible defects in the aeroplane to thwart them. He held that over-cautiousness was a policy that was actually less safe than pushing ahead keenly; for example, there were fewer accidents among people who were flying what he called vigorously, because by this means they came to have greater knowledge of their aeroplanes and were less likely to succumb to difficulties in flying. He would certainly suggest, therefore, in reference to the Service scouts, that they should be flown inverted, with the proviso that flying was carried out with the gentleness of hand which was taught to every pilot when he learnt to fly. On the one side we witnessed the engineer and scientist steadily improving the aeroplane; on the other the pilot exploring its possibilities and not wasting his talents. That was the way that progress had been made, and it was the only way.

SOME ASPECTS OF AERONAUTICAL PROGRESS

BY MAJOR-GENERAL SIR F. H. SYKES, G.B.E., K.C.B., C.M.G., M.P., F.R.AE.S.

A Paper read before the Royal Aeronautical Society (Scottish Branch).

It is very kind of you to invite me again to address the Scottish Branch of the Royal Aeronautical Society, and I am glad to do so at this the opening meeting of what promises to be a highly valuable session.

I will not excuse my temerity in coming here to-night for two reasons. First, since I am no longer in direct touch with aviation I do not claim first hand knowledge of detail, my interest in what we all believe to be one of the greatest of modern developments is still unabated. And secondly, because aeronautical progress must be assisted by open discussion of its difficulties, and it may be of value, whether you agree with them or not, to express some personal ideas from the outside angle of a year's private membership of the House of Commons as a preface to your more technical meetings.

The present Government has had a difficult air heritage to handle. Aeronautics, like many questions such as trade and unemployment, Empire consolidation and development, European conditions, reparations and the Ruhr, agriculture and the like, has reached an important milestone. Not least amongst such problems are those of communications and defence which, from now onwards, must largely depend upon the air. The issue requires great balance of judgment. A narrow-minded policy at this stage may lead to future disintegration; a broad, far-seeing one to the development and close linking up of the Empire.

The air, as we know it, has been evolved in the short space of fifteen years. Under right guidance it holds the developments of the future. As an instrument of war it will enforce operations in three dimensions. Air power may destroy the civilised world or at best render a country a menace to its neighbours. Air transport, as an agent of peace, can be a strong factor in the welding of civilisation. As the fastest locomotion ever known, independent alike of sea and land frontiers, it is bound to have a far-spread beneficial effect.

The civil and military, each with their independent *rôles*, are yet indissolubly intertwined, and any apparent stressing of the military side is only because the war, its requirements, and the fact that money was then of no consequence, played such a great part in bringing aeronautical progress to the position in which we know it.

There is not time to-night to deal in more than the barest outline with some aspects of the subject. But it is worth while to try to see something of what is or is not going on and, as far as possible, how we stand.

At the outset it is clear that all is not well with British air power. The experience of the past five years emphasises the fact that it is by research and operation that progress can best be maintained. Real aeronautical progress has been practically at a standstill since 1918.

Wide questions of politics have a direct effect. In 1919 there were two groups of problems confronting the air. First, the responsibilities for Imperial Defence and the inter-relation of the Navy, Army and Air. And second, how best to retain and utilise the necessary service portion of the instrument which the war had produced and, whilst looking upon the balance as a reserve, to turn as much of it as possible into an organisation of the greatest value to peace. That is to say, to hold the scales and to develop the two branches in their correct functions and proportions.

So far as the first group is concerned, Britain and the Empire are no longer protected by the sea, and air armaments have added greatly to the complications of Imperial Defence. In European warfare it will be impossible, until air superiority has been gained, for fleets to move, armies to mobilise and operate or the organisation of reserve resources of material and man-power to make headway. There are, in addition, the difficulties of defining the principles to which the services should direct their efforts; the extension of the areas of possible theatres of war; the increase of the vulnerability of the United Kingdom; and the necessity to secure the Empire and its communications as a whole.

Air power opens a new phase and sphere of war. Its radius, approaching 1,000 miles at 150 miles per hour, will increase and its action will be countered by nothing short of superiority in the air. An uncountered offensive will compel the removal of seats of government and naval, military and air bases beyond its radius of action. For these reasons, our first-line air strength must be equal at home to that of any other Power.

In this connection you will have seen an increasing number of articles supporting or denying the necessity for the Navy to have its own air arm and an announcement of the compromise recently approved by the Cabinet. There has been much controversy on this subject for the past three years. Personally, I think the compromise will be impossible of satisfactory working. A sound system is mainly dependent upon good organisation and correctly placed authority. It cannot rely entirely on goodwill. There is no doubt that the Air, the Navy and, in a lesser degree, the Army, have each a strong case in this matter. The real trouble is, of course, that the Air was allowed after the war to sink to an inadequate strength and to be ill-organised for its essential functions. Attack is the best defence and the primary requirement in war is an independent long-range air fleet supported by home defence units. Any factor which detracts from this must give way until reasonably adequate independent strength is assured. Theoretically, the arguments are in favour of all air being organised as separately as all sea or land forces, and it would obviously be unsound to revert to the old arrangement under which the Navy and Army had their own competing air services; but practically, on the other hand, their efforts will be ineffective unless they are allowed a more suitable system of control over the air units required for their particular purposes than has been the case. A generally satisfactory solution is almost impossible under any financial conditions that are likely to apply in this country, but I think it will be found necessary, sooner or later, to permit the Navy to have at all events a trial test of its scheme to run the personnel of its own air units; the control of the independent air force, of research, experiment and supply remaining with the Air Ministry.

A serious factor is that difficulties between the fleet and the air will tend to increase rather than diminish if matters are allowed to drift owing to gradual loss of touch by the air and the disappearance of those ex-naval officers now with the R.A.F., who have been mainly responsible for whatever has been effected by the R.A.F. naval air units. Already the last ex-sailor on the Air Council is being replaced by an ex-army officer, while three at least of the comparatively small number of senior ex-naval R.A.F. officers are on the half pay list.

As far as work with the Army is concerned, co-operation with the artillery is said to be good, but close reconnaissance poor owing to lack of knowledge by the observers of ground tactics and troop operations.

Let us turn to the second group of problems—the internal re-organisation of the air on a systematic, proportional, progressive policy.

The war left us with the finest flying service in the world; we are now aerially defenceless against at least one Power.

In war the Air must strike before the Navy and Army and will immediately suffer heavy casualties; the percentage of fighting men in the R.A.F. is very

small; only a fraction of the total air establishment do any day-by-day work in the air, and we have no reserve of trained personnel to fill the gaps.

Vast supplies of aircraft material must promptly be forthcoming; the British industry, the greatest and best equipped in 1918, has shrunk to attenuated, ill-nourished proportions, whilst that of France has been retained at a considerable size.

In the event of war there will only be time to carry on in production with designs which have been produced and tried out in peace; comparatively little has been done in this important aspect, whilst operational experiment also is stagnant. America has taken the lead in research and experiment—witness her recent success in the Schneider Cup contest at Cowes—and France in operation.

Air power, like sea power, and in this we have no less an authority than Captain Mahan, must intrinsically be based on a broad reserve of commercial effort and achievement. Expenditure on a purely military basis involves an ever-increasing deadweight as defence necessities increase; expenditure on a military spear-head and civil-shaft basis promises an eventual provision of air defence force at a minimum State outlay. Air transport, quite apart from its value as a reserve, has the strongest of claims, and is not camouflaged militarism; the utility of a self-supporting mercantile air fleet is obvious, but the development of British commercial aviation by lighter-than-air craft has hitherto been disregarded and by heavier-than-air brought to a quite diminutive result.

Technically, aviation has a broad trinity of inter-dependent aspects—design, new construction and experimental and normal operation—no one of which in peace can progress without the help of the other. And service aeronautics must be dependent upon this trinity, unless it is merely to rely upon a crude effort to achieve its results by the unnecessary expenditure of vast sums of money. From the service point of view, as I see it, the principle underlying all these matters should be the maintenance of the smallest possible regular forces compatible with safety, and the largest and most easily obtainable reserves of personnel and material; the greatest allocation of mental and financial resources to research and experimental work; the carrying out of all possible duties on the most economical and efficient procedure—that is on commercial lines—thus allowing the net to be most widely cast for the necessary reserve power. This principle has been disregarded and war ratios have been maintained. It is difficult to arrive at a precise figure, but in the Budget for the last completed financial year the funds allocated for the fighting branch were in the order of £14,000,000 and those for research and operational development were £2,000,000, or say seven to one, and even of this sum only a small fraction was devoted to true research. The proportion adopted by France, on the other hand, is about three to one.

In this connection it is, I think, regrettable that, as a matter of administration, the division hitherto made in Air Ministry estimates between expenditure on research and expenditure on service construction has been eliminated with the possibility of a departmental transference to meet excess expenditure on service standard equipment of funds intended for research.

The first question of policy to be decided is whether Britain really believes aviation to be worth while or not. The main problem is, of course, largely one of finance. Progress in any of the applied sciences is almost entirely governed by the amount of funds available to meet the cost involved. But even if the total sum granted is too small there is always a right and a wrong policy for the allocation of whatever is available. As a rule, if Great Britain does a thing at all she does it better than any other country. But in this matter the comparative results are that in 1922-1923 with a budget of about £18,000,000 we had thirty-two squadrons and, in size, a negligible "trinity," and France with an expenditure of 600,000,000 francs, or £12,000,000 at 50 francs to the pound, had some 200

squadrons and, as a "trinity," a strongly supported technical and operational industry and reserve of personnel, material and design and manufacturing resources. Again, even within the number of our service squadrons, it would appear that those in India—not perhaps technically, yet undoubtedly morally, largely the responsibility of the Air Ministry—are still unsuitably equipped for their duties. Indeed, the whole of the Royal Air Force itself—for which the Air Ministry is responsible—is still equipped with the identical scouts, two-seater fighters, day bombers and night bombers which were in use five years ago. Furthermore, it is very doubtful whether any even single particular machine in the possession of the Royal Air Force could come within 50 miles per hour of the speed of 266 miles per hour recently attained by the American Curtis Navy Racer. The Americans are rightly looking for quality as against quantity.

The present position then can hardly be described as a happy outcome of five years' policy. The first political régime asked for time in which they could, as they said, "cut away the rank growth of war and well and truly lay the foundations" of British air power. At all events the policy had a nearly four years' run. Action on erroneous principles once started takes a lot of undoing, and whilst I think the present Secretary of State, faced with a most difficult task, has tried hard and done many things of considerable value in lesser ways, very little advance if any has yet been effected in major policy. He appears, indeed, as far as fundamental matters are concerned, to have accepted the situation and, with the same weight of military advisers, the country is still reaping the same results.

The methods adopted since the war, whilst entailing very heavy expenditure, have ignored the basic necessities of progress.

We are now, it was announced in the House of Commons on 26th June last, to have an additional 35 squadrons for home defence at an immediate annual cost of £500,000, rising in three years to an annual cost of £5,500,000, and since this date a further increase up to 52 squadrons has been promised, but the requisite financial outlay has not yet been mentioned. No statement has been made as to any consequent increase in research while the unfortunate elimination of a separate research vote effected at the same time, lends itself to a raid on the pre-existing research mite to assist in meeting the cost of equipping these squadrons. I agree entirely in the necessity for additional squadrons, but further to reduce the proportion of air funds devoted to research or to take away the little which research hath, whatever holy writ may say on this score, is a continuance on even worse lines of the policy adopted since the war.

As taxpayers, we want the least amount compatible with safety spent on defence, but also as taxpayers we have a right that what is spent is utilised to the best advantage. Financial stringency has properly reduced the air vote to the lowest possible level, but the bulk being allocated to first-line defence, first-line defence wrongly and detrimentally has determined the general rate of aeronautical progress.

These being the results it would seem that the allocation is unsuitable; that though the basis of air work is flying, the greater proportion of those in the Air Force do no regular flying; that insufficient importance has been attached to purely aeronautical development; that insufficient funds have been expended in research, and that, in the absence of material orders for new equipment for Air Force units, constructors have been unable to finance experimental work and progress has been checked at its source.

Since the war the progress of service aeronautics has amounted to little more than the production in quantity of types which were in existence in an experimental stage in 1918.

The only material additions are the development into troop-carriers of the earlier large commercial passenger machines; the development for service uses of

the Amphibian which was first brought into being at the Civil Aviation Competition in 1920; and, in the case of lighter-than-air craft, the development of the mooring-mast during the short period in which airships were under civil control.

Efforts have also been addressed to producing efficient fleet co-operation machines in which we were undoubtedly very short at the end of the war, owing to the requirements of the Army. In the majority of cases these machines are fitted with engines which—in their early stages in 1918—have recently been sufficiently developed to render them suitable for service equipment.

Design, Research, Experiment and Operation

Let us now turn to the many fields of great potentiality which await us, but which can only be furthered by work and money laid out on the soundest basis of development, that is, upon design, research and development derived from experimental and operational use.

Research brought aeronautics into being and its progress much depends on full-scale and model experiment. A great deal has been and is being done by the Aeronautical Research Committee, the N.P.L. and R.A.E. within their financial limitations, but more and more research is necessary merely to maintain, let alone advance, the present rate of progress. Expenditure on research is one of the best of economies in life and material. It would repay us considerably to increase rather than to "axe" its scope. It and its operational trying-out, day in and day out, by civil flying are the seed, root and trunk of positive as against negative direction.

But while I think the proportion and net sum allowed for research have been too small, additional mistakes have been made. For instance, disregarding the necessity that the work of the designer, constructor, experimenter and operator should be sympathetically co-ordinated by an independent sound homogeneous governmental organisation of good technical and administrative calibre, the existing government department responsible for research is subservient to the fighting department of the air staff of the Royal Air Force. Then, too, instead of concentrating on aerodynamic and engine essentials and an increase of purely experimental flying, much of the small sum of money research has received has been wasted in the production of military fitments, the provision of which is of secondary importance. The production of new experimental types of aircraft has been delayed and their cost increased by the insistence that such machines should be fully fitted with the latest military equipment before trial is made of their aerodynamical efficiency. Covered with gadgets, machines take the air for their trials long after such tests should have been completed, and the expenditure and trouble devoted to their military equipment is wasted as the aircraft are not fit for issue to the service until the normal process of elimination of defects is completed by the construction of modified machines.

Two reforms in organisation are desirable if research is to receive the attention it deserves. First it should be under the immediate control of a technical official of high scientific attainments employed on a civil basis, and equally important it should be administered by a civil staff of technically qualified officials promoted on merit within their own department. Co-ordination of service interests with the progress of research could be adequately secured by attaching a succession of serving officers to this department.

The greatest technical requirements are those of the rapid development of the aeroplane as a safe, reliable and economic vehicle; greatly improved control; the improvement of useful load and range; increase of speed in getting off; reduction of head resistance; reduction of landing speed, elimination of stalling and nose-diving; increased reliability and durability of engine; reduction of fuel and oil consumption.

Then in the important matter of engines, effort has been solely concentrated on the production of high performance engines of military type which were in the experimental stage at the end of the war. The results, if slow, have certainly been good, as witness the high-powered 1,000 Napier "Cub," the 600 Rolls-Royce "Condor" and the air-cooled radial engines, the 350 to 400 Bristol "Jupiter" and the 350 Siddeley "Jaguar."

The only addition which occurs to me is the Beardmore heavy oil engine, but this is not yet in production, and in view of its very high importance for civil development in a probable large reduction of running costs should, I suggest, have received governmental assistance on a bolder policy.

The demand for a really commercial engine has been consistently side-tracked. The numbers of such an engine required are too small as yet to permit a manufacturer to recoup himself for the heavy initial outlay. An aero engine is necessarily a very costly article, and it is in just such a case that assistance can very usefully be given.

All existing engines, excellent in their way, were designed for military purposes, and lasting qualities were therefore sacrificed to light weight and high efficiency.

Safety depends primarily upon keeping the air. Endurance, simplicity and accessibility are qualities for which air transport firms would willingly pay in quite considerable increase of engine weight and consequent reduction of paying load. When it is realised that the 3s. per ton mile, which may be taken as the present minimum cost of air transport, includes something over sixpence per mile as the cost of engine maintenance, inspection and overhaul, and that, in addition, a large percentage of the comparatively high insurance rates charged are due to lack of confidence in present engines, the importance of suitable engines is apparent.

There are fortunately some signs that the importance of this matter for the development of commercial aviation is now being realised at the Air Ministry. But it requires bold handling to achieve the necessary results.

Taking it all round and considering the lack of support given, it is remarkable how much, though greatly less than should have been possible, has been achieved.

Two lines of research, for instance, in which progress has been made are those of the slotted wing by Mr. Handley Page, which gives improved performance and control, and that of metal construction, of which more than one type of aircraft is now undergoing prolonged trials, and of which there is no need to stress the value for use in the tropics or under conditions of widely varying temperature and humidity.

As regards the development of lighter-than-air craft events have, it would seem, compelled a reversal of the official attitude, and the Government have announced their intention to try out the modern airship, with commercial co-operation —under commercial control—on the long distance oversea routes. Technical details of the proposals have not yet been announced, but I would sound a note of warning that where the unit of operation is so large, costly and experimental, it is vital that however slowly development takes place, whatever allocation of funds is necessary, only the best equipment that research and science can give, whether on the ground or in the air, should be employed if the undoubted potentialities of the airship are to be fairly explored.

Our experiments have been carried out in the past with ships designed to out-manœuvre an enemy whose constructional and operational experience was greater than ours. The Pulham experiments, though clearly demonstrating the efficiency of the mooring-mast, which is essential to commercial running, were hampered by the opportunist nature of the equipment which was employed. With plant designed with every care for the purpose for which it is to be employed,

XUM

and provided that all concerned in the operation of the ships face from the outset, the fact that minor set-backs must be expected and be overcome, progress as in the case of heavier-than-aircraft should be definite and cumulative. The recent five-day flight of the French (late German) Dixmude is evidence of the potentialities of the airship, and progress is also marked by the new 400 horse-power Maybach airship engine which recently completed a continuous 29-day bench run at full power, at a fuel consumption of .403lb. per horse-power hour.

In America unlimited expenditure on a wide field of research and development has supported the efforts of designers and there has, in consequence, been a great stride in general aeronautical progress in the United States, where the performances of latest types far surpass those achieved in Europe. There are many examples; as a recent instance, America has secured first and second place in the Schneider Cup race. She holds the world's records for speed, altitude and endurance. This is entirely due to the way that she has concentrated on research. She is, incidentally, the only country equipped with a compressed air wind tunnel in which results can be obtained directly comparable with full-scale without the need for " scale effect " correction.

It is in the U.S. also that the development of the airship is being seriously pushed forward. Whether or no there is truth in the Press reports of an immediate trans-Atlantic service, it is clear that America is prepared radically to tackle the various problems concerned and generally to utilise the experience of the world.

The progress of air operation in this country since the war has been hampered, equally if not even more so than research, by an inadequate governmental and official length and breadth of view and realisation of the importance of the early development of a healthy civil transport industry.

There is need for more thorough full-scale tests of progressive types by commercial operation. Military operation affords a comparison with the last best. Civil operation provides a striving towards the next best.

The reason that air transport has not succeeded more rapidly and extensively is insufficient steady support (*a*) by the State and (*b*) by the public.

If the State believe in the necessity for aviation they must bear to a greater extent (whether by increased orders to firms or by indirectly assisting firms to meet costs) the expenditure involved by firms in experimental and research work.

Orders should be boldly and freely given to the construction industry to assist in the evolution of progressive types and these should be lent to the transport industry to try out in daily operation.

The little that has been done has, however, been well done. The existing routes to the Continent show a steadily progressive trend in regularity and in traffic. The recent tragic accident on the Manchester route emphasises by contrast the remarkable degree of safety that has been reached in the operation of the services. No such accident had occurred for over two and a half years during which over 1,500,000 miles were flown by British air transport firms.

The service to Berlin, in spite of international difficulties preventing it from becoming a regular daily service, has already shown by its results that it fills a commercial need, and the attraction of a seven-hour journey against one of 24 hours by rail and sea is meeting with response from the travelling public.

A beginning has also been made with a very important line of development; that of an oversea service by flying boats. This development—the Southampton-Channel Islands experimental service—is carried out in a zone subject to some of the worst flying weather in the world. The equipment used on the service is standing up to its work, and the experience gained in surmounting the difficulties, whatever its immediate financial results, will be of great value on more distant Imperial routes.

The service from Manchester has been disappointing owing, I think, primarily to conditions of bad visibility to which Manchester is subject.

The experimental mail service between Plymouth, Manchester and Belfast is one of promise, and definitely corrects the disadvantage under which these northern cities suffer in receipt of the American mail as compared with Continental competitors.

I gather from the Press that this experimental service has re-raised the question of communication between Belfast and Glasgow, and the establishment of a service taking one hour to one and a half hours should not present insuperable difficulties.

On the oversea routes the R.A.F. service between Cairo and Baghdad continues. It carries out a useful function, but having military considerations primarily in view and being operated under military control, it is naturally costly and does not tend towards development to a commercial basis.

Development elsewhere on the Imperial routes appears to have been held up pending decision in regard to the airship scheme. Malta aerodrome has, however, been completed and the cross Mediterranean facilities it offers will tend to induce air traffic along the Malta route to the East and assist Malta to attain in the air the position she holds on the British sea chain. Similar commercial air ports should be organised on the Imperial routes if British air power is to be free to operate in the defence of Greater Britain.

Here I would stress the importance of development of the Southern rather than the Central European route to the East.

The Southern route is the route to fine weather and stable flying conditions; it is the route upon which we can utilise British resources at British air ports and avoid the interference and complications which arise from unsettled international conditions now or in the future.

To reach the Near East by the Central European route, on the other hand, involves flight over France, Belgium, the Rhineland, Germany (or Austria), Czecho Slovakia, Hungary, Roumania, Bulgaria and Turkey, and leaving aside altogether present conditions which we hope are only temporary, the risk of future complication caused by international difficulties to an air service established on such a route as this is very considerable and very serious when such a service depends entirely on smoothly effected connection throughout its length for its efficiency.

Incidentally, in my opinion, the established mobile squadron organisation for home defence should be overhauled; non-flying personnel should largely be found by an auxiliary civilian reserve, facilities should be given for the training of pilots for and in civil transport and as many aerodromes as possible, other than experimental grounds, organised on a civil basis.

Turning to another aspect, air transport has gained considerable experience on the business side and in the improvement of the technical details of organisation. Progress in efficiency of administration is a development of the utmost ultimate importance. As regards the machines employed, the main progress following the adaptation of war designs to commercial work has been the production and try-out of the first, and as such, the first experimental commercial aircraft; useful load per horse-power has been increased, comfort bettered and noise to some extent reduced; while many of the causes of engine failure have been eliminated by the redesigning of fuel and cooling systems on operational experience.

A great deal, however, remains to be done to make machines more fool-proof and reduce the effect of possible human error, present in every form of transport, to a minimum.

XUM

As far as personnel is concerned, routine medical examinations of civil pilots are carried out every six months, and as the statistics so obtained increase, it becomes more evident that it is possible to look forward to a long flying life for the majority of pilots who take up this work as a profession.

One of the most serious results of the so-called policy of "cutting away the rank growth," however, has been the disintegration of the nation's pilot strength.

Refresher courses for ex-pilots on the Reserve have now been started at civil schools, but because of the absence of flying facilities which has occurred in the meantime for those pilots who did not remain in the R.A.F., the air industry, small as it is, is already hard put to it to carry out its services. And, while reserves of marine craft pilots have been allowed practically to disappear, no action has yet been taken to provide marine flying courses under the Reserve.

There is a great deal yet to be done, but the reliability of the air services shows steady improvement, and although the best of the existing aero engines still leave occasion for very considerable reduction in running and maintenance cost, weather or rather low visibility is the chief obstacle to regularity.

Improvement in material securing a high degree of inherent stability and controllability and a sense of confidence against breakdown will go far to counter bad visibility, but so long as the human element is employed progress in mist penetration is necessary if regularity equalling that of rail transport is to be attained.

Night flying tests have been carried out and have shown that the problem of night flight is the problem of daylight flying with the fog, mist or low cloud difficulty intensified. The ground organisation laid down after the war on the London-Paris route has proved, in the absence of conditions of low visibility, sufficient for regular operation of night services.

The importance of overcoming this remaining difficulty, caused by conditions of bad visibility, cannot be over-estimated, for until night flying is a regular practicable proposition the hours gained in the day are largely lost during the night, and the advantages of the air's speed are, with few exceptions, negatived in the transmission of mails which are the heart of commerce and for which the organisation of commerce utilises the night.

Whether, therefore, from the point of view of securing complete regularity in daylight air transport or from that of bringing into being a 24-hour flying day, there is ample scope for research and development in solving this problem.

Perhaps the most noticeable progress in commercial aviation is shown by the figures of costs. Two or three years ago exceptionally favourable conditions alone would permit running cost to be brought as low as 10s. to 11s. a ton mile; during this last summer the over-all cost under the best conditions in at least one instance, I believe, averaged for a month under 3s. per ton mile. This result demonstrates one of the advantages of the principle of "no monopoly." It is true that duplication of overhead charges involves expenditure which has to be met as a cost of competition. But, on the other hand, reduction in running costs is largely due to the system of intensive use of plant introduced into the industry by competition. Any tendency to carry to excess that intensive use must be carefully watched, but the fact remains that the principle was introduced by the competitive system, has been adopted in principle by all operating firms and is responsible, together with design developments, for a large proportion of the reduction in running costs which has been effected. That is not a result which would have been compelled by any foreign competition we have been called upon to meet.

Personally I am against the monopoly in principle. If the problem were merely one of purchasing the greatest possible number of flight miles in the current year, then support to a monopoly undertaking should give the greatest

results for available expenditure. If, on the other hand, the industry can still show advance in economic running, then the competitive system, though it involves a more patient waiting for mileage achievement, will more speedily attain to running on the most efficient and economic footing. And when the stage is reached of carrying out services on a self-supporting basis, then expansion of mileage and utility is automatic and almost limitless. Such expansion and the opportunity of becoming the world's air carrier will be the reward of the nation which first achieves economic air transport.

However, the Air Ministry have recently decided that the advance so far made should be consolidated and they are, therefore, about to place one firm in a monopolistic position by subsidising it alone. It is claimed that, whilst the immediate effect will be to eliminate British competition, in a short time the subsidised firm, if efficiently managed, should be on a paying basis without a subsidy, and that other British firms will then face it as unsubsidised competitors.

Whether State assistance designed to set the industry on its feet is given to a monopoly company or to two or more competitive firms, the manner of its allocation remains open.

The frankly military subsidy based on the quantity of aircraft maintained and of personnel on the pay roll can be left out of account as offering no hope of eventual discontinuance.

The remaining alternatives, payment on revenue earned and payment on mileage flown, have both been in operation in this country.

The former clearly offers the greatest incentive to operating firms. The difficulty in applying it is that neither the State nor firms have reliable traffic data upon which a fair percentage rate can be assessed. The result therefore must be that a rate too low involving unavoidable loss to the operating firm or one too high involving excessive payment of State funds is likely to be fixed. If the principle of subsequently revising the rate in the operating firm's favour is admitted, the firm's incentive to make economic progress is destroyed.

On the other hand, payment on a mileage basis, besides encouraging irregular and purposeless flying, suffers to some extent from the same difficulty in assessing rates.

The solution would appear to lie in a long dated guarantee of support on a scale decreasing annually, with a proviso that profits in excess of a reasonable return on capital should be returned, not to the Treasury, but should be devoted to increased research.

Consideration might also well be given to the possibilities of subsidising two groups, each with a zone, but with these zones overlapping and the overlap increasing annually until any monopolistic feature is eliminated.

In either event a factor of the greatest possible importance is the personnel of the Board.

As an instance of the progress of civil aviation in another direction the use of aircraft as a speedy and economical aid in fighting forest fires in Canada should be mentioned. In one case, selected from many similar instances, a serious fire was reported, the scene of which was distant two days' journey by ordinary methods. Using an F_3 flying boat, which was operated to and from a lake close by, the fire was got under control by the morning after the first report was received.

On one journey this machine carried nearly 5,000lbs. useful load, and on its last journey from the fire carried twelve passengers in addition to its crew.

In the provinces of Ontario and Quebec also during last year over 19,000 square miles were surveyed, and nearly 800 square miles photographed, from the air.

A letter which I have recently received says:—

> "If every Government in the Empire were to adopt the policy of using aircraft in every service under their jurisdiction, where they could be efficiently and in the broadest sense of the word economically employed, our problem in regard to air power would be largely solved. We have only touched the fringe of the subject in Canada, but the results obtained in the useful forms of flying show what can be done."

Undoubtedly much could usefully be done on this principle, especially where there is no military air force, but if development to a commercial basis is to take place, it should be on commercial lines and in commercial hands. Civil aviation properly developed offers the prospect of a commercial undertaking of national earning benefit. To allow it to remain under conditions where it merely carries out services, even services of great utility, without prospect other than that of indefinite continued cost to the State, is to risk its existence as an industry.

Of development other than that of commercial air transport an important one has been that produced by the recent reversion to the use of gliders and low-powered aeroplanes. When the 50 h.p. or more engine first came into use some thirteen years ago a cry went up from some that improvement in aerofoils would largely be stifled by the production and use of high-powered engines. Their voices were drowned by others who delighted in the prospect of flying projectiles hurled through the air by the brute-force of many cylinders. But the result of the restrictions placed on German aeronautics after the war was to turn the minds of her scientists back to the days of Pilcher, Lilienthal and the Wright brothers. With all the knowledge of piloting since gained and which those pioneers lacked, the Germans took up again the study of gliding and their example was quickly followed in other countries. As in the case of the early gliders, the next step has been to fit low-powered engines to the aircraft so produced.

Provided that the engines so used are strictly limited in power, and progress is obtained by improvement of the aircraft, exceedingly useful development may be expected, the results of which can then be applied in the case of commercial and military aircraft. Indeed, what may be termed amazing results have recently been obtained at Lympne.

At the same time the development of the cheap light aeroplane, whilst of great use in many ways, and especially in improving upon wind tunnel tests and in supplementing full-scale aerodynamic experiment, must not be relied upon to take the place of full-scale experiments which, though they entail great difficulty, should be much increased.

Some evidence that the development of civil aircraft is beginning to be realised to be important is given by the recent decision of the Air Ministry to purchase new British aircraft which will win the Aerial Derby or the Schneider Cup.

True, the aircraft in question would be of a racing type purely and simply. But for these races will be developed the latest ideas of designers for producing high speed aircraft, unfettered by military restrictions or any but a minimum of safety requirements.

Best methods of attaining speed will not be obscured by other factors, and from these special forms of aircraft will be bred the high speed fighting scouts of the future.

Without such an opportunity of recovering at least a portion of their outlay, few constructors can afford the expenditure necessary for entering for such events as serious competitors. Success in such widely advertised races, on the other hand, brings in its train foreign orders for the industry of the winning nation.

An example of this was the wide demand for Rolls-Royce engines after the series of long-distance performances for which they were used in 1919 and 1920; while the more recent fine performances of American aircraft had their repercus-

sion in a steady flow of orders for the Liberty engines held for disposal in England. The Air Ministry assistance, which enabled the British aircraft industry to provide their excellent exhibits at the recent Gothenburg Exhibition, will tend to attract more orders for British firms and thus provide such firms with further resources for carrying on their own lines of development.

This policy which has achieved success in Japan and in Sweden is capable of considerable expansion. A greater readiness to assist and encourage the training of foreign pilots in this country with British material, a greater State assistance, not merely in funds, to British training missions abroad and a broader view of the value of achieving success for British equipment in international events and international records are services which in their indirect results would amply repay the State. Civil missions such as that which went to Japan should be fostered, and expeditions, demonstrations and record-breaking assisted.

This is an aspect of development in which our French trade competitors have received far greater assistance than has been given to the British industry.

Air attachés abroad, foreign missions assisting sales and carrying out training with French equipment have their part in the development of the French air industry and at home State encouragement is still given to eliminating competitions for civil aircraft.

Speaking as I have been to the converted, I have not thought it necessary to postulate the utilities of the conquest of the air. I should like, however, to emphasise its importance in one direction. Year by year, almost day by day, events are forcing the conclusion that it is to the British Empire that we must look for our continued existence and for the well-being of the State and its citizens. Geographical conditions are the outstanding factor which tends to prevent fuller utilisation throughout the Empire of its resources. Air development can greatly help to surmount these difficulties.

I am as convinced as ever of the great future of aeronautics. Nothing can stop its growing importance to the nation and the world. No one who has the faintest understanding of the difficulties expects it to come in a flash. Its advance, though unparalleled, has been borne on the track of sacrifice and toil, and an immense amount of patient thought, courage and work lie before those engaged in it. It wants wise and adequate assistance. Too much is involved for it to be allowed "to worry through somehow." We can only hope that in honour to those who have gone, to assist those now in it and to come, and bring lasting benefit as we believe to the world, that the Government, assisted by the Imperial Conference now sitting in London, will give sound redirection, reinforced impetus and increased breadth of vision to its guidance.

ASSOCIATE FELLOWSHIP EXAMINATION,

September 24th-25th, 1923

Aerodynamics

(Time allowed, three hours.)

Six questions only to be answered.

1. Explain, with the help of diagrams, a method of estimating the lift of a wing from the surface pressure distribution. If the method were extended to the question of drag, what discrepancies would you expect and how would these arise? Briefly describe a scheme for obtaining the measurements in actual flight.

2. Define "Drag coefficient." Go carefully into the question of whether this quantity is a constant, establishing any formula you may use and illustrating your answer by means of an example.

   In comparing the drags of airship envelopes a different coefficient is commonly employed. Define this and explain its advantages.

3. State Bernoulli's theorem.

   The static pressure at a certain point above an aerofoil held in a wind channel working at 60ft. per sec. is observed to be less than that of the undisturbed stream by 1.2in. of water. Calculate the velocity at this point, stating the assumption you make in applying the theorem. Explain why a similar calculation applied to a position immediately behind (*a*) the disc of rotation of an airscrew, (*b*) a bluff obstruction in the airstream, would lead to error.

4. Sketch the section in general use for streamline wires. Discuss the considerations leading to the choice of this section. What other factors should be taken into account in choosing a section for exposed struts?

5. An aeroplane weighing 3,200lbs. has a landing speed of 40 m.p.h. The wing system gives the following results on test:—

Lift coef.	.093	.171	.243	.299	.465	.505 (max.)
Lift/drag	7.0	11.6	13.6	12.7	9.3	5.5

   A 1/10th scale model of the remainder of the aeroplane is found to have a drag of 0.85lb. at 60ft. per sec.

   Assuming the thrust h.p. developed to be 160, estimate the maximum horizontal and climbing speeds at low altitude.

6. The thrust diagram of a two-bladed airscrew, 9ft. diameter, may be taken as triangular; the thrust being zero as far as 9in. radius and at the tip, and having a maximum value at a radius of 4ft. The airscrew is fitted to an aeroplane weighing 3,000lb. whose overall L/D ratio at 120 m.p.h. is 6.7; 200 B.H.P. is required at this speed, the airscrew turning at 1,400 r.p.m.

   Find (*a*) the thrust per ft. run at a radius of 3ft. 6in.

   (*b*) The apparent increase of angle of incidence required at this radius to allow for inflow.

   Take the ratio of the inflow factor to the outflow factor as 0.35.

7. A monoplane, 36ft. span, weighing 1,450lb., has a speed range of 45 to 80 m.p.h. The lift coefficient varies uniformly from zero at 3° to 0.52 at +10° and its maximum value is 0.65. While at full speed the machine is given an angular velocity of 0.3 radians per sec. about its longitudinal axis. Calculate approximately the instantaneous value of the rolling moment damping out the disturbance.

8. Briefly discuss what is implied when an aeroplane is said to be "inherently stable." Explain the function of a dihedral angle on the wings in contributing towards stability.

9. Describe fully a method of testing the maximum speed and climb of an aeroplane. Your answer should be as complete as possible and include notes on the reductions you would make to standard conditions.

Mathematics

(Time, three hours.)

Full marks will be obtained by answering correctly *five* questions or their equivalent.

1. A simple pendulum is allowed to oscillate under gravity from an initial position of rest and angular displacement α. If the medium exerts a resistance on the pendulum bob proportional to the velocity, determine how the successive amplitudes of vibration diminish.

2. A motor car, left unattended on a long incline of 1 in n, starts to descend under its own weight. If the combined road and air resistance expressed in lbs. per unit mass of car is found to be $R = a + bv^2$ where v is the speed in ft./sec., find the speed attained after any time t, and the limiting speed.

3. Define:—Moments and Products of Inertia; Principal Axes of Inertia.
Given one Principal Axis at a point of a rigid body, show how the other two may be found.

4. State precisely what you understand by the terms:—Equilibrium; "stability or instability to small disturbances," describing the process and principles you would utilise to investigate these conditions.

5. Explain the dynamics of gyroscopic action, treating a simple case in detail.

6. Explain what is meant by a determinant and show by an illustration that the product of two determinants of equal order is itself one of the same order.
Prove

$$\begin{vmatrix} x^3 & x^2 & x & 1 \\ \alpha^3 & \alpha^2 & \alpha & 1 \\ \beta^3 & \beta^2 & \beta & 1 \\ \gamma^3 & \gamma^2 & \gamma & 1 \end{vmatrix} \equiv (x-\alpha)(x-\beta)(x-\gamma)(\beta-\alpha)(\gamma-\beta)(\alpha-\gamma)$$

7. At noon a person standing on a cliff h feet above sea level observes the altitude of an airship in the plane of the meridian to be α, and the angle of depression of its shadow on the surface of the water to be β, the sun being behind the observer. Show that if γ be the sun's altitude at the time of the observation, the height of the airship above the surface of the water will be

$$h \sin\gamma \sin(\alpha+\beta)/\sin\beta \sin(\gamma+\alpha)$$

XUM

8. If $x=a$ is a first approximation to a root of the equation $f(x)=0$ show that a second approximation is $a-f(a)/f'(a)$. Hence, or otherwise, find the roots of the equation

$$5x^3+2x^2-3x+1=0$$

correct to two significant figures.

9. Describe the method or methods you would adopt to determine the value of a definite integral of a function you could not integrate formally.

Illustrate with

$$\int_0^{\frac{1}{2}} dx/\sqrt{(1-x^4)}$$

10. Evaluate

$$\int_0^a dx\sqrt{(x^2+a^2)}$$

$$\int_0^{\pi/2} \sin^n x dx \,.\, [n=+ve \text{ integer}]$$

11. Solve the equations:—

$$d^2x/dt^2-2a\,(dy/dt)+b^2x=0$$
$$d^2y/dt^2+2a\,(dx/dt)+b^2y=0$$

12. Show that if any function of the complex quantity $x+iy$ be arranged in the form

$$U(x, y)+iV(x, y)$$

where U and V are real functions of the variables x and y then U and V are separately solutions of the equation:—

$$\partial^2u/\partial x^2+\partial^2u/\partial y^2=0$$

Deduce that $U=$constant and $V=$constant are systems of orthogonal curves.

Interpret these equations and properties in terms of any type of physical problem to which they apply.

ASSOCIATE FELLOWSHIP EXAMINATION,

September 25th-26th, 1923

Strength and Elasticity of Materials and Theory of Structures

Eight questions only to be attempted.

1. Explain the terms "limit of proportionality," "resilience," "hysteresis," "proof stress," "permanent set."

2. Describe a method of determining Young's modulus by a beam test in such a way that the deflection due to shearing forces is eliminated. Deduce a formula for determining E in terms of the deflection of the beam and the known properties of the beam.

3. Sketch and describe the apparatus used for applying the Izod impact test. Discuss the value of this test in connection with wood for aircraft construction.

4. An encastre beam 10ft. 0in. long is symmetrically loaded by two concentrated loads each of three tons placed at distances of two feet from the supports. Sketch the diagrams of bending moments and shearing force and give the maximum positive and negative values in each instance.

5. Deduce a formula for the maximum fibre stress in a slender strut when the load is applied eccentrically.

6. Obtain an expression for the maximum bending moment in pin-jointed member which carries an axial thrust and a concentrated lateral load at the centre of the span.

7. Describe the conditions of flight for which it is necessary to design the structure of an aeroplane.

   State the nature of the forces in the following members for each condition :—

   (*a*) Top front spar.
   (*b*) Bottom front spar.
   (*c*) Flying wire.
   (*d*) Anti-flying wire.

   Discuss the effect of positive and negative stagger on the nature and magnitude of the loads in the wing structure.

8. Determine an expression for the maximum shear stress in a box spar subjected to a given shearing force.

9. The fuselage structure shown in Fig. 1 is erected with no initial tensions in the bracing wires. Obtain by calculation the forces in the members AB, BC and AC when a load W is applied as shown.

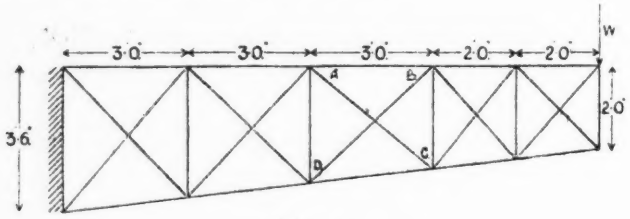


FIG. 1.

10. Obtain expressions for the minimum number of members required to brace a plane and a space frame respectively. If these conditions are fulfilled is this sufficient to guarantee complete bracing? Illustrate your answer by examples.

11. Describe in detail any method for determining the forces in a pin-jointed structure which contains redundant bars.

REVIEW

Over the Balkans and South Russia: Being a History of No. 47 Squadron, R.A.F.

By H. A. Jones, M.C. (Messrs. Edwin Arnold and Co.)

When the Expeditionary Force first crossed to France it was accompanied by four squadrons of the Royal Flying Corps.

At the end of the war there were 132 service squadrons on the various fronts, 16 home defence squadrons and some 200 training squadrons. In addition to the Western Front, where there were 100 squadrons at the date of the Armistice, the operations of the Royal Air Force ranged from the frozen forests of North Russia to the tropical swamps of the equator. The majority of these squadrons are now perforce disbanded and there is a real danger of their records as units being lost.

When the time came to decide which squadrons were to remain permanent a very difficult problem was presented which could never be satisfactorily solved. It is to be hoped that when the Air Force comes into its own all the war squadrons of the R.A.F. will be represented by worthy successors whose achievements can emulate but can never surpass those of the war-tried progenitors.

Unfortunately, the country's financial stringency has brought the production of squadron histories almost to a standstill, for no funds are available to assist in the cost of production. Publishers cannot be expected to take the risk of financial loss such publications may involve, much less the individual who may be keen enough to devote his spare time in writing the history of the squadron in which he was proud to serve during the war.

It is thus not surprising that only seven squadron histories have as yet seen the light of day, and their authors deserve credit for their courageous efforts.

Under the title "Over the Balkans and South Russia," Mr. Jones has written the history of No. 47 Squadron, a squadron which has a distinguished record of service in Macedonia and, after the Armistice, in South Russia. This squadron played no little part in establishing British air prestige in the Balkans. With Nos. 17 and 150 Squadrons it established an ascendancy over the enemy air services from the Gulf of Orphano to the banks of the Vardar. Equipped with machines which were always second rate owing to the demands of the Western Front, these squadrons displayed that indomitable persistence which earned them the profound respect of their foes.

The final offensive on the Macedonian Front, which began on the 14th September, 1918, and which resulted in the complete rout of the Bulgar, was the beginning of the collapse of the whole of the far-flung German forces. Next to Palestine this campaign affords a classic example of the influence of air power on a retreating army.

On the 21st September, the day when the Turkish Seventh Army was being shattered in Palestine, a reconnaissance by No. 47 Squadron established without doubt the fact of the Bulgar retreat. According to Mr. Jones

> "Our machines flew over in relays, and from low heights exhausted the ammunition from the machine guns against the unhappy Bulgars and bombed the columns of his transport, causing endless confusion. In many places the roads run alongside ravines and whole masses of transport were blown down these ravines, to crash in the gully below. At other points the roads cut through the mountain side, and bombs dropped here piled twisted lorries

and dead animals and men high on one another, blocking the way to the oncoming columns which, ever pressing on from the rear, blocked the line backwards. These congested, panic-stricken masses offered still better targets to our machines, of which every advantage was taken."

The position is well summed up in a telegram forwarded on the 26th September by the XVI. Corps to G.H.Q. :—

"The routes from Cestovo Valley to Kosturino show signs of indescribable confusion that must have existed in the retreat of the Bulgar Army. Guns of all kinds, motor cars, machine guns, rifles, and every kind of war material abandoned. Indicating that our R.A.F. must have contributed largely to bring about this state of things."

The book is well illustrated with maps and photographs and contains an introduction by Air Vice-Marshal Sir W. G. H. Salmond, K.C.M.G., C.B., D.S.O. Unfortunately a large number of places mentioned in the text are not on the maps and vice versa. Further, where names in the text do occur in the maps frequently the spelling is different. For example, Lake Langaza in the text occurs as Lake Langada on the map; Stojanova on the map is apparently Stojakovo in the text, and so on. This impairs the value of the book, making it difficult to follow the operations on the maps.

The book having been written from excellent official records appears to be free from errors of fact.

Mr. Jones served with distinction in No. 47 Squadron. On page 77 we find in reference to the work of the observers during the summer of 1917, "This reflected great credit on the squadron observers, of whom Lieutenants Boyd-Harvey, Harman and H. A. Jones were most active."

Mr. Jones deserves congratulations for having surmounted all the difficulties inherent in the production of a squadron history. His book is of an intimate nature, having the dash of a novel in parts.

"Over the Balkans and South Russia" will be read with pride not only by those members who served in the squadron but by the present members of No. 47 Squadron, in whose keeping the tradition is safe.

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CONTENTS FOR DECEMBER, 1923

		PAGE
1	NOTICES	567
2	THE AIR MINISTRY HELICOPTER PRIZES	568
3	"THE MANŒUVRES OF INVERTED FLIGHT," BY SQUADRON LEADER R. M. HILL, M.C., A.F.C.	569
4	"SOME ASPECTS OF AERONAUTICAL PROGRESS," BY MAJOR-GENERAL SIR F. H. SYKES, G.B.E., K.C.B., C.M.G., M.P., F.R.Ae.S.	606
5	ASSOCIATE FELLOWSHIP EXAMINATIONS	618
6	REVIEW	623

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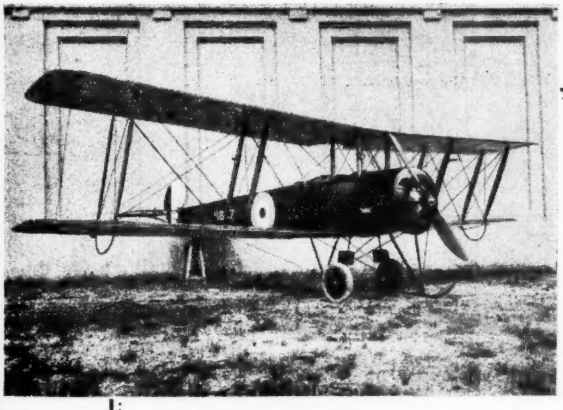

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